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TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

September, 1932

Founded by LOUIS A. BAUER
Conducted by J. A. FLEMING
With the Co-operation of Eminent Investigators

CONTENTS

(*Contents concluded over*)

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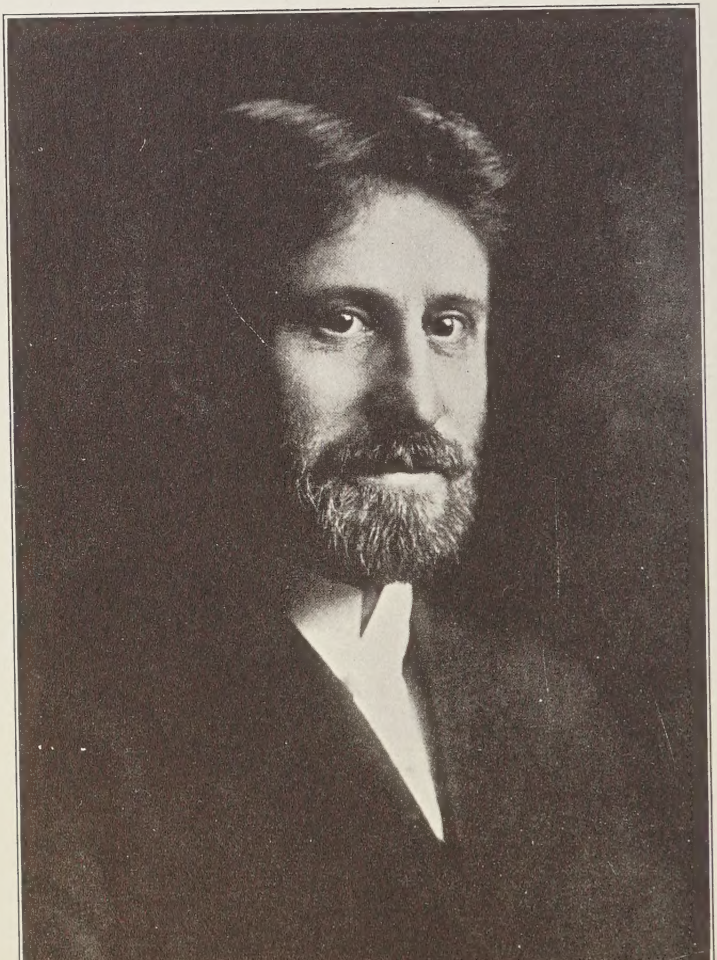


Sincerely yours,
Louis A. Bauer

Terrestrial Magnetism and Atmospheric Electricity

VOLUME 37 SEPTEMBER, 1932 No. 3

BAUER MEMORIAL NUMBER

This JOURNAL regards it a privilege to honor the memory of Louis A. Bauer, its founder, and from 1896 to recent years its editor. Therefore this number is devoted to articles in personal appreciation and to discussions of those varied themes within its field which engaged his active interest. Striking proof is afforded of the widespread contacts and friendships enjoyed by Dr. Bauer by the many parts of the world from which the articles have come, and by the long list of writers, all preeminent in the geophysical fields represented. Chief among them may be mentioned the dean of research in terrestrial magnetism, Prof. Dr. Ad. Schmidt, the privilege of whose friendship and counsel was Dr. Bauer's from their first meeting in 1893. Were it not for the limitations of space available, the number of contributors might readily have been doubled or trebled.

Dr. Nippoldt's statement regarding Dr. Bauer's scientific achievements and life is so complete that little need be added save perhaps some account of his travels. He was by no means an "easy-chair" scientist but took an active part from time to time in the more arduous field-operations under his direction. A large part of his success in conducting the world magnetic survey and in effecting international cooperation in that survey and at international gatherings was due to his first-hand knowledge derived from extensive travels undertaken chiefly in connection with his official work.

During his early career, while with the United States Coast and Geodetic Survey, he traveled widely throughout the United States and its territories making magnetic surveys and selecting sites for the magnetic observatories of that Survey established at Cheltenham, Maryland (1899), Sitka, Alaska (1901), Honolulu, Hawaii (1901), and Vieques, Porto Rico (1903). While abroad during September to December 1899 he compared survey magnetic instruments with standards at the Kew, Potsdam, Pavlovsk, and Parc St. Maur observatories.

He became Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in 1904 and in 1905 initiated the oceanic magnetic survey of the Pacific on the *Galilee*. Early in 1909 the construction of the non-magnetic vessel *Carnegie* was begun under his general direction and in the latter part of 1909 he sailed on her for the maiden voyage from St. Johns, Newfoundland, to Falmouth, England. In 1912 he again took part in the observational work on the cruise of the *Carnegie* from Colombo, Ceylon, to Port Louis, Mauritius, and return to Colombo. In October 1921 he joined the vessel at Balboa, Canal Zone, for an inspection of work and equipment and accompanied her to Washington.

He also actively took part in the land magnetic survey and investiga-

tions. Thus he initiated the program of simultaneous magnetic declination observations made in connection with the solar eclipse of May 28, 1900, he himself observing at one of the six stations, namely, Rocky Mount, North Carolina. It is believed that the results of this work gave for the first time an unquestionable record of a magnetic effect attributable directly to solar-eclipse phenomena. He also took active part in other eclipse observations in 1905 at Missinaibie, Canada; in 1911 at Tau Island, South Pacific; in 1918 at Corona, Colorado; in 1919 at Cape Palmas, Liberia; and in 1925 at Greenport, Long Island, New York.

In 1907, in connection with the inspection of the *Galilee* at Sitka, Alaska, he made a special investigation of magnetic anomaly near the local magnetic pole at Treadwell Point, Alaska, which he had discovered in 1900. During March 1911 to the early part of 1912, in the course of a trip of inspection of the magnetic survey on land and sea, he conferred with the heads of various magnetic organizations in Australia and Asia respecting the continuation and inauguration of many surveys. In 1919 after observations of the eclipse in Africa he represented the United States Weather Bureau at London in July at the conference of official weather bureau directors and also attended as a delegate the meetings of the International Research Council, of the International Union of Geodesy and Geophysics, and of other unions established by the Council at Brussels, Belgium. It was in this year that the Section of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics was established and Dr. Bauer was appointed Secretary and Director of its Central Bureau, an honor which he held until his selection for the period 1927 to 1930 as President of that Section. In 1922 he attended the Rome meeting of the International Union of Geodesy and Geophysics and returned to Washington via Western Australia and New Zealand, visiting en route the Department's Observatory at Watheroo, Western Australia, and for the second time the observatories at Bombay and Colombo. In 1924 he attended the meeting of the International Union of Geodesy and Geophysics at Madrid, Spain, and in 1927 that at Prague, Czechoslovakia. During these journeys he had the happy opportunity of visiting the great majority of the functioning magnetic observatories of the world and of making the acquaintance of their directors and staffs, thus establishing relationships invaluable in forwarding geophysical sciences.

Dr. Bauer always took advantage of the opportunities presented to observe the countries visited and the customs of their inhabitants. He collected and brought back much material on which his many interesting lectures of popular nature were based.

The contributions in this memorial number present from a few of his many colleagues and friends, both abroad and in his own country and Department, some of the many problems which he attacked and in the solution of many of which he made, or was the effective agent in making, real scientific advance. It is not too much to say that his work has had a large directive influence in the development of terrestrial-magnetic investigations during the past forty years and that the activities of the Department which he founded have splendidly realized his vision.

Dr. Bauer is survived by his widow, Adelia Doolittle Bauer, a devoted helpmate during their long life together, and by his daughter, Mrs. Robert W. Weeks and her two daughters. The JOURNAL is indebted to Mrs. Bauer for the portrait of September 26, 1909 used as a frontispiece.

LOUIS AGRICOLA BAUER AND TERRESTRIAL MAGNETISM[1]

By A. Nippoldt

On April 12, 1932, the fruitful and active life of Louis Agricola Bauer, director emeritus of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, came to an end. Seldom has it been given to an investigator to call into existence, in his own branch of science, an organization of such wide interests and on so large a scale, as Bauer did in his chosen field—terrestrial magnetism and electricity. In an exemplary manner, he placed in the service of science, a nature richly endowed with ideas and with the theoretical as well as practical ability. I esteem it a great honor, at the request of the editor of this Journal which Bauer founded, to present on behalf of international geophysical science, a picture of the activities and achievements of this investigator, by repeating the words which I published elsewhere[2] some seven years ago on the occasion of the sixtieth birthday of our departed friend. They were then dedicated to the living man and may now serve to express the lasting gratitude of his colleagues in all parts of the world. Honor be to his memory.

First a few words of biography. L. A. Bauer was born on January 26, 1865, in Cincinnati where he also received his scholastic training, obtaining the degrees of Civil Engineer [1888] and Master of Science [1894]. He began his practical experience [as civil engineer in 1886 and next] in 1887 as computer in the Coast and Geodetic Survey under Mendenhall and Schott, turning his attention especially to terrestrial magnetism. In order to perfect his theoretical knowledge, he entered the University of Berlin [October 1892] where he studied astronomy, mathematics, and physics, especially under von Bezold, Foerster, Fuchs, von Helmholtz, Kundt, Planck, and others. At that time the magnetic observatory in Potsdam had just been built, and on its earliest observational records may be seen the name of Bauer, as a volunteer observer. On January 12, 1895, he obtained in Berlin the degree of Doctor of Philosophy [and Master of Arts]. His dissertation bore the title: "Beiträge zur Kenntniss des Wesens der Säkular-Variation des Erdmagnetismus" [Contributions to the knowledge of the nature of the secular variation of terrestrial magnetism]. [In 1895 he was appointed docent in mathematical physics at the University of Chicago and] the following year [1896, instructor in geophysics at the same University. From 1897-1899 he was assistant professor of mathematics and mathematical physics at his alma mater, the University of Cincinnati. During the summers of 1896-99 he conducted a magnetic survey of Maryland as chief of the division of terrestrial magnetism of the Maryland Geological Survey and was astronomer and magnetician for two boundary surveys of Maryland 1897-98; in 1899 he was appointed occasional lecturer in terrestrial magnetism at the Johns Hopkins University. In the spring of 1899] he returned to the Coast and Geodetic Survey in

[1]Translated by H. D. Harradon. The translator's additions are enclosed in brackets.

[2]Naturw., **13**, 317-319 (1925).

Washington to become Chief of the newly created Division of Terrestrial Magnetism. While occupying this position he established a number of new magnetic observatories and conducted the magnetic survey of the United States.

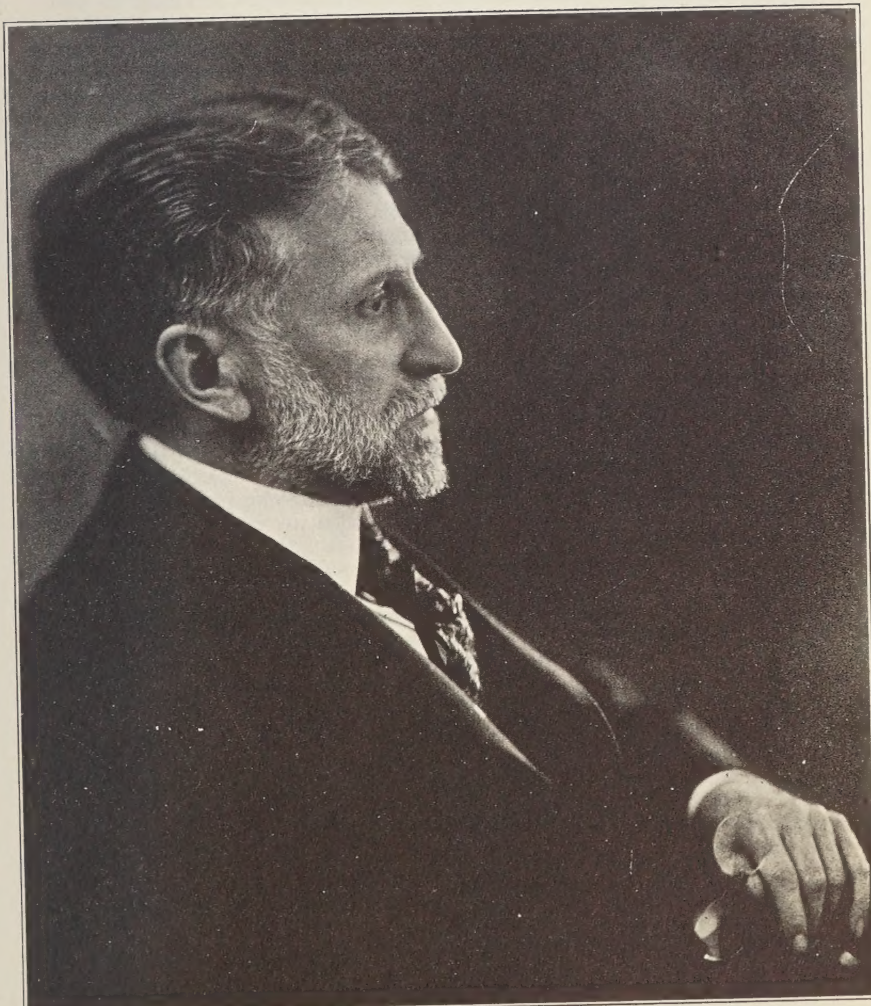
Thus in a short time he had added to his solid theoretical foundation, practical experience in the chief branches of magnetic observational activity, namely, observatory and field work. And now a work of organization was begun. The new Department of Terrestrial Magnetism of the Carnegie Institution of Washington was established [1904]. To the general public, it is only known that the new department was created and that Bauer was entrusted with its direction; we may, however, confidently regard him as its proposer. As compared with the Coast and Geodetic Survey, the Carnegie Institution is a private organization; indeed, according to its statutes, it is even an international one, which not only undertakes and supports American scientific enterprises but also those of other countries or of private individuals. Bauer conducted his Department along these lines, and if the special investigations of the Institution comprise the lion's share of the work, still there are many outside ones which have received through the Institution substantial support.

In addition to the above, Bauer founded [1896] the "International Journal of Terrestrial Magnetism and Atmospheric Electricity," a long-needed organ of our science, to which every investigator can contribute articles in his native tongue. [It is now in its 37th year.]

It is difficult to summarize the tasks which the Department of Terrestrial Magnetism of the Carnegie Institution now set itself to accomplish, for what held them together in all their many-sidedness was the plan, not so strikingly uniform to the outside view, and the clearly-defined purpose. as it existed from the beginning, in the person of the director.

First of all, it was necessary to fill in the gaps in our knowledge of facts, so that theoretical conclusions could be reached which would be really applicable to the whole Earth. Accordingly at his instigation or as a result of his own efforts, there were erected various new magnetic observatories in the hitherto neglected regions of the Earth, particularly in the southern hemisphere and the tropics. But his chief aim was the completion of the magnetic survey of the Earth which at the beginning of his career was still wholly insufficient, and hence did not permit the solution of the most essential theoretical questions. There were, in the first place, the vast unsurveyed expanses of the oceans as also the extensive tracts in the interior of the continents of Asia, Africa, Australia, and South America, to say nothing of Antarctica. It is hard to realize how ridiculously small was the surveyed portion of the Earth, upon which alone at that time all theoretical considerations rested.

Bauer set as his first goal the magnetic survey of the oceans. He secured a vessel, as suitable as possible for the purpose, which bore the name of *Galilee*; but she was soon replaced by the non-magnetic yacht *Carnegie*, equipped with auxiliary engine, and built especially for magnetic-survey work. Yet naturally the difficulties did not end with the work of constructing the vessel; a suitable set of new instruments which would give results of sufficient accuracy on a rocking vessel, had to be designed, constructed, and tested. How many problems had to be solved in this



LOUIS AGRICOLA BAUER

FEBRUARY 13, 1923

connection can only be imagined. But in the end Bauer's object was fully attained, since on the cruises of the two vessels, a well-planned distribution of magnetic determinations on all the oceans was secured.

While the ocean-work was in progress, numerous land expeditions were making magnetic observations in all parts of the world. Some of these parties were sent out directly by the Carnegie Institution, while others carried on the work with its support. The organization of these expeditions presented many problems. For instance, what a variety of means of transportation was required. Along the rivers of South America the motor-boat was employed, while the crossing of the desert from Algiers to Timbuktu was by camel caravan. Other modes of conveyance were found suitable for long journeys across Australia and China and for travel in the cold regions of North America. The preliminary results of these expeditions were made public with surprising rapidity, even in the course of the year after they were obtained, which justified the erection of a permanent building in Washington, where the reduction and compilation of the results are made [and the investigational and experimental work are conducted].

After this survey-work was well under way—but still long before its conclusion—Bauer turned his attention to the investigation of the fundamental theory, using at first as a basis the old observational data. The result was a series of papers on "The physical decomposition of the Earth's magnetic field." He divided the total field into the so-called uniform or homogeneous and the "residual" field; by the former is to be understood a field corresponding mathematically to a uniform magnetization of the Earth. Bauer showed that this field does not really owe its existence to a magnetization actually present, but to one of a different nature which changes from the poles to the equator as if influenced by the centrifugal force of the rotating Earth. He believed that here was a direct influence of the rotation, while others were partisans rather of an indirect one, that of the figure of the Earth, which is likewise modified by this centrifugal force.[3] While making these computations for different epochs Bauer discovered that the Earth's magnetic field not only is subject to the known secular variation in the direction of its axis, but also that the intensity of magnetization decreases at the same time. By the most recent computations made on the basis of all data at hand, this fact has been confirmed beyond doubt. Bauer specialized further these investigations, not only by taking into consideration the causes of magnetism residing inside the Earth, but also those existing outside, where the secular variations are much more pronounced.

There is still a third part of the terrestrial-magnetic field which is equivalent to a system of electric currents passing vertically through the Earth's surface. At first this was regarded as a purely computational result, or rather as a consequence of our insufficient knowledge of the distribution of the magnetic elements over the Earth. As the observational data increased, Bauer became more and more of the opinion that we have here to deal with real facts. If such a current exists, it is by far greater than the atmospheric-electric vertical current in the lowest layers. Thus it is easy to understand that Bauer soon began to give more and more attention to the measurement, on the Department's survey vessel, of the atmospheric-electric elements, and also the results here obtained

[3]Terr. Mag., **26**, 99-111 (1921).

are of great importance. He then gave his personal attention to the study of the relation of atmospheric electricity with terrestrial magnetism and solar activity, a question which pertains to the rapid temporal variations, rather than to the permanent field of the Earth, and thereby enriched our knowledge of atmospheric electricity more than of terrestrial magnetism.

The true connection between terrestrial magnetism and atmospheric electricity is furnished by the electric currents ever flowing in the Earth's crust. In these also, Bauer took an active interest, critically examining the existing data and methods and initiating new observations.

The desired physical explanations of the data of terrestrial magnetism once found, the question of cause or origin immediately arises. In this connection the circumstance that the uniform field is inclined only 11°.5 to the Earth's axis, looms in the foreground. It might therefore be possible, that the source of the Earth's magnetization should be sought in the rotation of the Earth. Hence, Bauer encouraged experiments being performed at the laboratory of the Department of Terrestrial Magnetism on the magnetization by rotation of bodies of different materials. These experiments which present great experimental difficulties, have already yielded very interesting physical results, but they are not yet finished.

Along with all these and in direct line with Bauer's investigations, are numerous contributions dealing with special problems which it is impossible to mention separately. Taken as a whole they constitute an excellent model for modern specialization. Every relevant question which comes up is attacked with full force, and always all information, which can be useful, from other scientific fields, is brought to bear upon it: Hence, specialization in the particular new work, with the entire field of knowledge as working material.

It is obvious that so energetic an example must exert a stimulating influence on other nations and specialists. And if, since the beginning of our century, research in terrestrial magnetism has shown a vigorous upward trend, we owe this to the intermediary of Louis Agricola Bauer.

Meteorologisch-Magnetisches Observatorium,
Potsdam, Germany

LOUIS AGRICOLA BAUER IN THE PROGRESS OF SCIENCE AS EXEMPLIFIED IN TERRESTRIAL MAGNETISM

By G. W. Littlehales[1]

It is indeed fitting that this issue of the International Quarterly Journal of Terrestrial Magnetism and Atmospheric Electricity should be selected to emphasize that this one, among the instrumentalities fashioned by Louis Agricola Bauer as tools of investigation in those earth-sciences which cluster about terrestrial magnetism, was the agency designed to be the expression of the record of progress. It was to serve the Olympian purpose—inspiring to him—to find the meaning of Professor Clerk Maxwell's passage, "What cause, whether exterior to the Earth or in its inner depths, produces such enormous changes in the Earth's magnetism, that its magnetic poles move slowly from one part of the globe to another? When we consider that the intensity of the magnetization of the great globe of the Earth is quite comparable with that which we produce with much difficulty in our steel magnets, these immense changes in so large a body force us to conclude that we are not yet acquainted with one of the most powerful agents in Nature, the scene of whose activity lies in those inner depths of the Earth, to the knowledge of which we have so few means of access."

Mirrored in this Journal, which, in its entirety, is a literary memorial to the earnestness of his endeavors, are the gathered means and resources—now monuments to the dignity of his aims—by which he brought into association the work to be done in the magnetic survey of the globe, the institution for doing it, and the men to direct and perform the researches to augment its results—unique shipping engaged in perfecting magnetic surveying on all the oceans, skillful observers penetrating the most remote lands with standardized magnetic instruments, and finally the Department of Research in Terrestrial Magnetism busy with the mathematico-physical analysis of the magnetic field of the Earth.

Bauer knew all the steps by which the science in which he cast his lot has ascended from the lodestone, and he had a just appreciation of the merits and achievements of the eminent men who had preceded him in this field of science—of Halley, Astronomer Royal of England, who wrote upon his chart "What is here properly new is the curve lines drawn over the several Seas, to show the degrees of the variation of the magnetical needle or sea-compass: Which are designed according to what I myself found in the Western and Southern oceans, in a voyage I purposely made at the Public charge, in the year of our Lord 1700; or have collected from the comparison of several journals of voyages lately made in the Indian Seas, adapted to the same year"; of Hansteen, who wrote the "Magnetismus der Erde" in 1811 and knitted up the previously scattered observations into maps of the lines of equal magnetic declination corresponding to successive epochs, from the year 1600 to the year 1800, and similar maps of the lines of equal magnetic inclination; of Sabine's fourteen communications to the Royal Society of England, entitled "Contributions to Terrestrial Magnetism," which enabled him

[1]Mr. Littlehales was the joint author with Bauer of the project originally submitted to the Trustees of the Carnegie Institution of Washington for the magnetic survey of the oceans and subsequently was for some time consulting hydrographer of the Department of Terrestrial Magnetism and the designer of the general features of the non-magnetic ship *Carnegie*; further, he was among the founders and earlier associate editors of the International Journal of Terrestrial Magnetism and Atmospheric Electricity.—*Ed.*

in 1840 to reach a much closer approach to the elements of terrestrial magnetism as manifested at the Earth's surface than have ever appeared in the world before Bauer's work; of Karl Friedrich Gauss, the first mathematician of the nineteenth century, who made the magnetism of the Earth an agency for the scientific investigation of terrestrial physics by measuring the terrestrial-magnetic force in terms of the fundamental units of space, mass, and time.

These eminent predecessors were all of foreign nationality. Bauer's devotion to research in terrestrial magnetism made him one of those who have aided in making the men of science in America leaders in this branch of inquiry during the present generation, and helped to dispel the tendency to disparagements among Americans of their own capacity in this regard ever since Alexis de Tocqueville published the prediction in the middle of the nineteenth century that the conditions of life in America would be inimical to the development of eminence in science. He belonged to the school of research students who are deeply interested in the applications of analysis to physical science, and gave evidence of his capacity as a mathematical physicist in a memorable series of investigations into the decomposition of the Earth's permanent magnetic field, in which the principal features of the distribution of magnetic forces on the surface of the Earth are considered to be roughly represented by harmonics of the first degree and are thus calculated and substracted from the actual forces in order to discover where the centers lie which render the surface-distribution unsymmetrical. In this manner, besides establishing relationships between terrestrial magnetism and other branches of geophysics, he was enabled to point to two systems of magnetic or electric forces, situated partly within and partly outside of the solid substance of the Earth, which in the course of time cause changes both in the direction and intensity of magnetization.

At the time of our joint application to the Trustees of the Carnegie Institution of Washington concerning comprehensive surveys of terrestrial magnetism, the threshold had been reached from which it could be clearly seen that the office to be performed in order to effect definite progress in the science of terrestrial magnetism consisted in discovering, by scientific measurement, the observational facts of the direction and intensity of the Earth's magnetic force, both over the land and over the sea, in every part of the world. Whereas, before this time, analysis was of necessity based upon observations made by unrelated observers with instruments not compared with one another nor with any common standard, and, accordingly, gave differing results for the use of the geophysicist and the navigator, now the observations were to become homogeneous.

In seeking to bring order and reliance out of this chaos of data, Bauer performed a signal service to the world of geophysics and to the use of the sea as the great highroad of transportation and communication, and it is so important a contribution that it must serve as a test for all present analysis as well as a foundation for all future researches in the subject, since science must be responsive to the events which have now been ascertained by the Department of Terrestrial Magnetism.

The labor involved in collecting the data, in discussing the observations, and in deriving trustworthy results necessitated, of course, absorption and concentration; but for a man so engaged upon a field so

recondite, he had a singular interest in matters near at hand and did not eschew diversions. These diversions, after all, formed but a slight fraction of his employment, and this latter was above all remarkable for the unity of its aim.

Along, with the advancement of this aim, which, creative in itself, was to forge the key to unlock the portals leading to a knowledge of the causes and the meaning of the magnetic characteristics of the Earth, there came abundant fruits to augment the potent influences which had flowed from the magnetic needle at least as far back as the beginnings of oceanic navigation. The official world-charts of the Variation of the Compass, of the Inclination of the Magnetic Needle, and of the Horizontal Intensity of the Earth's Magnetic Force, published by the Hydrographic Office of the Navy Department for the guidance of American shipping on the sea and for assigning the direction of the magnetic meridian in all sea-charts, severally bear a legend which tells that, in the foundation of their construction, there were employed the observations of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Whenever the non-magnetic ship *Carnegie* came homeward bound from far-called oceanic cruises, or whenever expeditions returned from their distant journeys to the far corners of the Earth, among the first obligations to be recognized was to communicate to the Government of the United States the observational fruits brought home, and, with like purpose for the security of shipping and the safeguarding of the lives of seamen, to the governments of other maritime States, and yet further to the governments of remote nations whose enlightened rulers had permitted the entrance of foreign observers into their national domain, in the interests of science.

United States Hydrographic Office,
Washington, D. C.

COOPERATIVE WORK OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM UNDER THE DIRECTORSHIP OF LOUIS A. BAUER—AN ACKNOWLEDGMENT

By H. U. Sverdrup

In Volume I of the "Researches of the Department of Terrestrial Magnetism" Bauer summarizes the first part of the program of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington by saying: "The chief endeavor is to secure magnetic results in the regions where most needed and where there are no organizations prepared to undertake the work."

Under Bauer's directorship the Department of Terrestrial Magnetism has, through its expeditions and observatories, contributed infinitely more than any other institution to the completion of the magnetic survey of the globe. When studying the volumes in which the results are published, the reader is impressed not only by the vast amount of information but also by the painstaking care which has been exercised to develop adequate instruments and to facilitate the work of the observers.

The experience gained with regard to instruments and methods became invaluable whenever the Department, in full accord with its

program, cooperated with expeditions to regions difficult of access and to which parties could not be sent for the sole purpose of magnetic-survey work because of prohibitive expense. I do not intend to give a general review of this cooperative work of the Department, but merely to point out that it has not only supplied expeditions with excellent instruments but has also, because of its thorough preparations, given the observers of expeditions a moral support, the value of which cannot be overestimated. I have learned this from my own experiences during 1918 to 1925 when in charge of the scientific work on Roald Amundsen's Arctic Expedition with the *Maud*.

Bauer's friendship with Amundsen dated from 1906, when Amundsen returned from his journey through the North-West Passage on which he, during two years, had undertaken magnetic observations in the vicinity of the North Magnetic Pole. Bauer was greatly interested in these observations and offered to reduce and prepare them for publication, but Amundsen felt under obligation to have this work carried out in Norway. He, therefore, declined the offer of assistance, but was so vividly impressed by Bauer's sincere interest that he strongly desired to establish an intimate cooperation with the Department of Terrestrial Magnetism for future expeditions. In 1918, when preparing the *Maud*-Expedition he returned to the question and received most generous help.

The results of the work of the Expedition within the fields of terrestrial magnetism, atmospheric electricity, and auroral research were published by the Carnegie Institution of Washington in 1927. I shall not enlarge upon these results, but I wish to emphasize that they were obtained not only through the efforts of the members of the Expedition but to a still greater degree as a result of the foresight and insight shown by the Department in selecting the scientific equipment.

Attention was given to every detail and no single item was overlooked. The completeness of the equipment naturally facilitated the daily work, but besides this, the thoughtfulness and care evidenced in every detail, exerted a moral influence of great value. Every little thing which had been supplied to the expedition by the Department of Terrestrial Magnetism attested a genuine love of the work for which it was intended to be used, and this love was an inspiration to the observers who were to carry out the work. The very fact that the instruments with accessories and instructions were flawless, aroused in the observers a desire to make use of the equipment to the best possible advantage and convinced them that their efforts would be appreciated. It gave them the backbone which is needed on a long, isolated expedition. It is, therefore, correct to say, that credit for the magnetic work that was accomplished on the *Maud*-Expedition is due not only to the observers but in a very large measure to the director of the Department of Terrestrial Magnetism and his associates.

I am convinced that the same has been experienced on the many other expeditions with which the Department of Terrestrial Magnetism has cooperated and that the observers of these expeditions join me in a feeling of sincere gratitude towards Bauer, who inspired them to do their utmost because of his keen insight in the problems to be investigated and his deep knowledge of human nature.

CHR. MICHELSENS INSTITUTE,
Bergen, Norway

THE MAGNETIC SURVEY OF NEW ZEALAND

By C. Coleridge Farr[1] and Henry F. Skey[2]

L. A. Bauer's connection with such magnetic work as has been done in New Zealand was continuous from 1895 until ill health prevented him from taking so active an interest in these things.

We remember well, in the days before observational work on the magnetic survey of New Zealand was begun, his support in the proposals that were being put forward, and how intensely valuable that support was when matters had advanced enough (about 1897) to bring the proposal before the notice of the New Zealand Government.

We here, in New Zealand—a British Dominion—turned perhaps naturally to Kew Observatory for a lead, and to the Kew Committee for aid, rather than to the United States Coast and Geodetic Survey—for the Carnegie Institution of Washington was not then established—but in those days we kept up a correspondence with Bauer and his sympathy in our proposals was of the greatest assistance.

At this time and of course for several years prior to 1898 Bauer had as Editor of Terrestrial Magnetism many opportunities of pushing the claims for a more intensive study of the facts as well as theories of terrestrial magnetism, and these opportunities he used to the utmost. He was always particularly insistent on the necessity for more observational work in the southern regions of the Earth and his advocacy, both editorially and in the papers by eminent magneticians he published, assisted us greatly. One of these latter was by Dr. Adolf Schmidt and it strongly recommended the establishment of a magnetic observatory here in New Zealand. Altogether the whole tone of Terrestrial Magnetism at this time, which reflected Bauer's own views, was such that in pushing for the establishment of a magnetic observatory here, one felt he had the support of every one interested in terrestrial magnetism. It was from this Journal, which he started and edited for so many years that one learned these facts, as it is also in that same magazine that we now lament his going. It was thus really more by the help he gave us in letting us know the views of others than in any other personally public way that his warm support and sympathy with our effort was manifested.

However, in 1900, again when the Carnegie Institution of Washington was established and even more in 1904 when its Department of Terrestrial Magnetism was organized, we felt indeed the powerful aid of his backing.

We remember how we rather expected to be taken seriously to task by Bauer when we wrote to Terrestrial Magnetism saying that as far as Christchurch was concerned we intended not only to run our magnetographs at high speed during the actual International term-hours arranged for the *Discovery* and the *Gauss* but to continue during the whole 24 hours at that speed. We had arranged with Mr. Bernacchi of the *Discovery* that we would do this and that he—if he had any reason to suspect that magnetic disturbances of importance were in progress

[1]Professor of Physics, Canterbury University College, Christchurch, N. Z.

[2]Director, Magnetic Observatory, Department of Scientific and Industrial Research, Christchurch, N. Z.

would run his instruments for a longer time. Instead of receiving the proposal to thus interfere with international arrangements in stony silence, Bauer rather supported the proposal and indeed arranged that some of the United States instruments should overlap us. Unfortunately the days chosen as term-days in 1904 were exceptionally quiet and although we did keep going for the whole 24 hours on all the days there was no marked disturbance on any of them.

It was in August 1905 that the great work of the complete ocean magnetic survey of the world, initiated by Bauer, was commenced; he then had commissioned the *Galilee* for this special research, and made in her an experimental voyage from San Francisco to San Diego, in order to fix upon observational methods. No one was better fitted for the superintending of this great project, his previous experience on vessels of the United States Coast and Geodetic Survey, being especially valuable.

It was inevitable in the course of this work, that contact should occasionally be made with the various magnetic observatories throughout the world. Christchurch, New Zealand, then the most southern magnetic observatory in the world, had been already visited in July 1907, by an observer, Mr. G. Heimbrod, of the Department of Terrestrial Magnetism, but actual contact with the sea-work was first established on Christmas Eve, 1907, when the *Galilee*, under the command of Captain W. J. Peters, moored alongside the breakwater in Lyttelton Harbour at 4 p.m.

A fairly long stay was necessary, and after shore observations and observatory comparisons were completed, she sailed on January 17 for Callao. It was on this first visit that one learned to appreciate the good judgment of Bauer in the selection of men for an arduous task.

In 1908 Bauer, recognizing that the world magnetic survey was really a work of world-wide interest, decided that it would be of great advantage to foster the interest already exhibited by various governments and institutions, and in the south Pacific area, appointed a New Zealander, Mr. (now Dr.) Edward Kidson to his staff of observers. After assisting in work on the outlying islands of New Zealand, and in Australia, Mr. Kidson was allotted work on the *Carnegie*, and subsequently very successfully carried out the main recent portion of the magnetic survey of Australia. We see here then Bauer's effective sympathy with local effort, and his recognition of the international character of pure scientific advancement.

Not, however, until November 3, 1915, did the *Carnegie* reach Lyttelton, staying until December 6. This was our second contact with the sea-work, and was preliminary to the great southern circum-polar cruise of the vessel, which was completed by her return to Lyttelton on April 1, 1916, when she was docked and remained until May 17, sailing on that day for Pago-Pago. The late Captain J. P. Ault at this time commanded the vessel, and it is now possible to remark that this gentleman mirrored the sterling qualities of his chief.

Bauer himself first visited New Zealand and the Christchurch Observatory in May 1911, and very pleasant recollections of that visit are retained here. His kindly personality and eager desire to advance terrestrial magnetism influenced many in this part of the world, causing them to regard pure research with a more friendly eye. His practical help and interest in the local work was evidenced by his sending an observer, Mr. W. C. Parkinson, to reobserve at ten of the stations of the Magnetic

Survey of New Zealand from February to April 1916, when also two new stations in the Lake District of Otago were occupied. The unfortunate world war inevitably restricted scientific work of this kind, but in 1922 Bauer was able again to include New Zealand in his range of operations, and Mr. D. G. Coleman, reobserved at seven of our stations.

On October 20, 1920, the *Carnegie* with Captain J. P. Ault in command, on Cruise No. VI, revisited Lyttelton, and an intercomparison of standard instruments was obtained, the vessel remaining in port until November 19.

Bauer, himself, revisited New Zealand in July 1922, and the writers had the great pleasure of meeting him in Wellington, and, for the first time, had the privilege of hearing him lecture on an important part of the general research into terrestrial magnetism, the subject being "Recent advances in the knowledge of earth-currents." It was also then that one was able to draw his attention to the revealed fact that the secular march of horizontal magnetic force at Christchurch had been found to be related to the heliocentric longitudes of the planets, and herein also Bauer revealed the unprejudiced spirit of a true scientific man.

Now that he has gone we can but recall vividly the scene of our last handclasp, and his last heard farewell words. New Zealand is grateful, on her own behalf and on behalf of world science, to a great worker, an untiring organizer, and a brilliant mind guided by the spirit of Truth.

Canterbury University College (C. C. F.),
Department of Scientific and Industrial Research
Magnetic Observatory (H. F. S.),
Christchurch, New Zealand

THE DEVELOPMENT OF THE MAGNETIC SURVEY OF CANADA

By W. E. W. Jackson

The untimely death of Dr. Bauer cast a gloom over the whole world of magnetism. His enthusiasm was contagious and had spread throughout all lands. We in Canada were early affected by his influence and are now happy to join in a "Memorial" fitting his achievements. He will always live in the minds and hearts of all who were privileged to have known him.

At the time of the founding of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, magnetic science in Canada had fallen to its lowest state. The Toronto Observatory had in 1898 been forced to find a new location on account of the development of the local street-car system. When the variometers were remounted at Agincourt some thirteen miles northeast of the old site, some difficulty had been experienced with the vertical-force instrument, and so it was allowed to fall into disuse, and records were obtained only from the *D*- and *H*-variometers. Even absolute observations were only made at irregular intervals oftentimes months would elapse between them.

In 1906, on the suggestion of Bauer, one of his observers, P. H. Dike, who was making a magnetic survey in northern Canada, visited Agincourt to compare his instruments with the standards in use there. The contacts established between the two departments at that time have

been continued to the great advantage of magnetism in Canada. As a direct result the improvement of our instrumental equipment, to bring it up to the standards set by the Department of Terrestrial Magnetism under the leadership of Bauer, has been our constant aim and now some twenty-five years after the first intercomparison, we feel we have attained our objective. In 1910 a magnetometer of the type developed from the great experience of Bauer and his colleagues and manufactured in the intrument-shop of his Department was secured, followed in 1912 by a Toepfer earth-inductor. In 1914 a vertical-force variometer of the Adie pattern was installed and for the first time since the removal of the instruments from Toronto, complete records of D, H, and Z were obtained.

The latest addition to the equipment at Agincourt was made last year, when a Schuster Smith coil-magnetometer was obtained from the Cambridge Instrument Company of England and set up as the standard at Agincourt for absolute measurements of horizontal force. A short account of some results obtained with this instrument is to be found in the March 1932 number of the Journal.

The present magnetic survey of Canada is also a direct result of the 1906 contact. Spasmodic surveys had been made in the past, notably that of Lefroy in the 40's of last century and those of Fawcett, Ogilvie, King, Deville, and Klotz, during the 80's. King was successful in establishing the Dominion Observatory in 1904 and with the assistance of Klotz, a department undertaking geophysical investigations was started about 1907. The lack of data on terrestrial magnetism which made it necessary for the Department of Terrestrial Magnetism of the Carnegie Institution to send a party into Northern Canada to secure such information, also established the need for a complete magnetic survey of Canada. This was begun by Klotz and is still being carried on. About the same time the Dominion Surveys Branch, which was doing a great deal of work in Western Canada, found considerable need for correct magnetic data and required their field observers whenever they had their instruments set up and positions and azimuths determined to also take readings of compasses attached to their theodolites and thus some thousands of observations have been secured as a by-product of the survey. Standardization was done at Agincourt.

This again brought up the need of an observatory in Western Canada to provide means for correcting field-data for diurnal, annual, and secular variations. In 1916 the Meanook Magnetic Observatory was started. The counsel and support of Dr. Bauer in this undertaking was sought and graciously given and much of its success is directly due to the inspiration for magnetic work which his enthusiasm aroused wherever he went.

Meteorological Service of Canada,
Toronto, Canada

LOUIS A. BAUER AND THE ZI-KA-WEI OBSERVATORY

By J. de Moidrey, S.J.

My scientific relations with Bauer extended over nearly four decades, dating from the time when I was appointed director of the Magnetic Service of the Zi-Ka-Wei Observatory. It was also about this time that he began the publication of his invaluable international Journal of Terrestrial Magnetism. It has now happened that his death has coincided almost exactly with my retirement from active service and this fact has impelled me to contribute a few lines to this special number dedicated to his memory.

In addition to the great interest which Bauer has manifested through all these years in our magnetic work in China, I believe that he took a special interest in the series of more or less disconnected studies which I was able to publish from 1918 to the time of my retirement a few months ago. These papers which are of very unequal value, bear the title of "Etudes sur le magnétisme terrestre." They consist of 39 studies embracing about 350 pages, with a considerable number of graphs. It is not easy to evaluate the debt that these papers owe to Bauer.

In two of the papers, photograms are reproduced in full size for 1919, and somewhat reduced for 1924. These curves differ little from those usually published in observatory bulletins. A very useful feature of the first, however, not usually given in similar publications, is the reproduction of very calm curves. There is some doubt whether an American or European magnetician, not having first seen the paper, would realize what is understood here as a very calm curve.

The movement of a freely suspended magnet was on several occasions taken into consideration, in the XY-, YZ-, and ZX-planes. The diurnal and annual variations are of interest; it is a striking fact that, though small and elongated, they are in a clockwise and anti-clockwise direction in several cases. Such considerations were first made by Bauer at an early date, and I have made extensive use of similar graphs in my Etude of last year.

The satisfactory conditions of our photograms facilitated the attempt to make a review in Etude XXIV of 47 years' records on correlation with seismological registrations. This study was undertaken as a result of the perusal of a communication of Bauer in August 1909. It was our intention to resume this work in 1924, but this was not found possible.

The last of our Studies which appeared a few months ago, with the collaboration of M. F. Lou, is concerned with the secular variation in the Far East covering nearly the whole western coast of the Pacific from the Arctic Ocean to Australia. From the remotest times for which reliable magnetic data could be obtained, the secular variation was always very small, so much so, in fact, that the old Chinese name for magnet, the south-pointing needle, is nearly as applicable now as it was three or four centuries ago.

For ascertaining many variations of short duration, which are expected to reveal a periodic appearance, chiefly daily change, monthly means are undoubtedly the most satisfactory. In general fewer and somewhat

longer periods, for example, the seasons, are preferred. It is to be regretted that the four natural seasons were discarded and three seasons of four months introduced, namely, winter (November, December, January, and February), summer (May, June, July, and August), and the equinoctial months (March, April, September, and October). Bauer was opposed to the introduction of this third, hybrid season and in my Studies I have endeavored to vindicate, successfully I hope, the soundness of his views in this matter.

There is a great difference between the equinoxes and we are not justified in attempting to establish the existence of an equinoctial type or in inquiring into the particulars of this wholly artificial season. Let us take, for example, the daily inequality of declination; the summer months are remarkably homogeneous, and the winter months hardly less so, though differing from the former. But what result can we expect to obtain from the two spring and autumn months, at best an artificial mixture? In fact, it cannot be greatly different from that of the summer months, but it cannot be distinctly equinoctial. The two equinoxes if restricted to five days each, are altogether different and cannot lead to a single type of inequality.

The annual variation of the principal magnetic elements was considered several times. In declination, very uncertain, and in all cases, very small results were obtained. In force the results were more satisfactory, although the total range hardly exceeded one gamma. A maximum at the solstices and a minimum at the equinoxes cannot well be denied which fact reminds one of the daily curve of H. In the case of the inclination, the total range is about $0'.6$. But, in this element, the maximum occurs at the equinoxes and the minimum at the solstices. Thus the effects of the Earth's rotation and revolution seem to be of the same kind. A more satisfactory conclusion could hardly be expected.

In reviewing these few pages, it appears that I was never requested by Bauer to undertake any particular study nor did he ever suggest to me any investigation, yet I am not the less conscious that my Etudes, whatever their value may prove to be, owe much to him—to the reading of some of his well-pondered notes, or lighting upon a few stimulating phrases. There was much leaven in him for which I will always remain very grateful.

OBSERVATORY OF ZI-KA-WEI,
Shanghai, China

THE MAGNETIC SURVEY AND OBSERVATORY-NET OF THE UNITED STATES

By N. H. Heck

Seldom is it given to a mortal to dream a great dream and then live to see its realization. Such an experience was granted to Louis Agricola Bauer. His dream came a little before the beginning of the present century, and, when about a quarter of that century had passed, it was far on the way to realization. The dream related to the covering of the entire Earth with accurate measurements of terrestrial magnetism and allied phenomena so that scientific studies could be made for the Earth as a whole.

At the start the opportunities appeared small with only the State of Maryland as a field. However, his field grew and he grew with it; first the United States and the regions under its jurisdiction, and then the entire Earth. His important place in bringing about these results is evidenced by the three-fold monument to his memory, represented by three accomplishments, any one of which is enough to establish a permanent claim to fame.

The first was the development of a world-wide viewpoint of the problems of terrestrial magnetism. His establishment of the International Journal of Terrestrial Magnetism and Atmospheric Electricity has done much to contribute to such a viewpoint and to coordinate international activity.

His second great accomplishment was the organization of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. This organization has accomplished the double purpose of making magnetic observations in those parts of the land where the countries themselves do not make such observations, as well as in all the oceans, and of undertaking world-wide studies of terrestrial magnetism and allied phenomena. Its accomplishments and future possibilities are well-known.

Less associated with him in public knowledge, since it was fairly early in his career, was his third important accomplishment -the part which he took in developing the standards of accuracy in magnetic work and the magnetic work itself of the United States Government through the Coast and Geodetic Survey. The work at present, with some modifications, is following the plan worked out by him when he was Inspector of Magnetic Work of the Coast and Geodetic Survey. Five widely spaced magnetic observatories are in operation, for four of which he selected the sites, and three of which have operated continuously since the start, more than thirty years ago. It is largely due to his initiative that the United States has made important contributions in the field of terrestrial magnetism.

The mystery which he sought to solve still appears as far from solution as ever, but this does not mean that his contribution was in vain. All the resources of science are being marshaled and steady progress is being made. Then too, very practical uses have been developed, some of which were beyond his conception and that of everyone else when the original plans were made. His name will forever stand high among the pioneers of the most elusive of earth-sciences.

United States Coast and Geodetic Survey,
Washington, D. C.

PRINCIPAL PUBLISHED PAPERS OF LOUIS A. BAUER

By H. D. Harradon

The total number of contributions to knowledge by Louis A. Bauer alone, or by him in collaboration with others, exceeds 300. These include research papers, scientific reports, lectures, magazine articles, notes, etc. Aside from his favorite field of investigation terrestrial magnetism—he has to his credit important papers dealing with magnetism, atmospheric electricity, various aspects of terrestrial and cosmical physics, and thermodynamics. To enumerate all these papers would transcend the limits of the space here available, and accordingly only a summary of the chief publications will be attempted.

Physical decomposition, theory, analysis and origin of the Earth's magnetic field—On this subject there are 17 papers, published chiefly in Terrestrial Magnetism and Atmospheric Electricity during the period 1899-1923. The last paper "Chief results of a preliminary analysis of the Earth's magnetic field for 1922" (Terr. Mag., **28**, 1-28, 1923), contains the results of the latest mathematical analysis of the Earth's magnetic field based on the magnetic data resulting chiefly from the world-magnetic survey conducted by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Summaries of method of analysis and conclusions drawn are given in Science, **58**, 113-115 (1923) and Nature, **112**, 295-298 (1923). Among the principal papers belonging to this group are the following:

The physical decomposition of the Earth's permanent magnetic field. Terr. Mag., **4**, 33-52 (1899); **6**, 13-24 (1901); **8**, 97-129 (1903); **9**, 113-133; 173-186 (1904).

The physical theory of the Earth's magnetic and electric phenomena. Terr. Mag., **15**, 107-128; 219-232 (1910); **16**, 33-52; 113-122; 233-236 (1911); **17**, 79-96, 115-140 (1912).

On the origin of the Earth's magnetic field. Phys. Rev., N. S., **1**, 254-257 (1913).

A consistent theory of the origin of the Earth's magnetic field. J. Wash. Acad. Sci., **3**, 1-7 (1913).

Secular variation of the Earth's magnetism—During the period 1892-1923, 15 papers were devoted to the discussion of the phenomena, internal and external systems of operating causes, and theory of secular variation.

Beiträge zur Kenntniss des Wesens der Säcular Variation des Erdmagnetismus. Dissertation, Univ. Berlin. 56 pp. with 2 pls. (1895).

On the distribution and the secular variation of terrestrial magnetism—Nos. I, II, and III. Amer. J. Sci., **50**, 109-115; 189-204; 314-325 (1895).

On the secular motion of a free magnetic needle. Phys. Rev., **2**, 456-465 (1895); **3**, 34-48 (1895).

Is the principal source of the secular variation of the Earth's magnetism within or without the Earth's crust? Terr. Mag., **4**, 53-58 (1899).

Note on the secular motion of the Earth's mean magnetic axis. Terr. Mag., **6**, 73-75 (1901); also Proc. Amer. Assoc. Adv. Sci., **46**, 58 (1897) and Science, N. S., **6**, 757 (1897).

The seat of the principal cause of the secular variation. Terr. Mag., **8,** 112-118 (1903). [The Earth's total magnetic energy was computed by rigorous methods for the first time and for various epochs, 1829-1885, and it was found that there had been a steady diminution in the Earth's magnetization, a result which was confirmed by the analysis for 1922.]

Systems of magnetic forces causing the secular variation of the uniform portion of the Earth's magnetism. Terr. Mag., **9,** 173-186 (1904).

Zur Theorie der Säkularvariation des Erdmagnetismus. Physik. Zs., **12,** 445-448 (1911).

Vertical earth-air electric currents—Six papers were devoted to the subject of a non-potential portion of the Earth's magnetic field, or line-integrals of the magnetic force. The first paper "Vertical earth-air electric currents" appeared in Terr. Mag., **2,** 11-22 (1897). The latest results are given in "Chief results of a preliminary analysis of the Earth's magnetic field for 1922" in Terr. Mag., **28,** 1-28 (1923).

Investigation of magnetic effects during total solar eclipses—Bauer initiated, beginning with the eclipse of May 28, 1900, a definite plan of magnetic and allied observations which was realized during eleven eclipses. The chief results thus obtained may be found in the following papers:

Résumé of magnetic observations made chiefly by the United States Coast and Geodetic Survey on the day of the total solar eclipse, May 28, 1900. Terr. Mag., **5,** 143-165 (1900).

Report on the magnetic observations made in North America during the total solar eclipse of May 17-18, 1901. Terr. Mag., **7,** 16-22 (1902).

Results of international magnetic observations made during the total eclipse of May 18, 1901, including results obtained during previous solar eclipses. Terr. Mag., **7,** 155-192 (1902).

Magnetic and allied observations during the total solar eclipse of August 30, 1905. Science, N. S., **22,** 411-412 (1905).

Magnetic inspection trip and observations during total solar eclipse of April 28, 1911, at Manua, Samoa. Carnegie Inst. Wash., Pub. No. 175, **2,** 201-209 (1915).

On the results of some magnetic observations during the solar eclipse of August 21, 1914 (in collaboration with H. W. Fisk). Terr. Mag., **21,** 57-86 (1916).

Results of magnetic and electric observations made during the solar eclipse of June 8, 1918 (in collaboration with H. W. Fisk and S. J. Mauchly). Terr. Mag., **23,** 95-110; 155-190 (1918); **24,** 1-28, 87-98 (1919).

Résumé of observations concerning the solar eclipse of May 29, 1919, and the Einstein effect. Science, N. S., **51,** 301-311 (1920).

Results and analysis of magnetic observations during the solar eclipse of May 29, 1919. Terr. Mag., **25,** 81-98 (1920).

Solar activity and terrestrial magnetism—

Concomitant changes in terrestrial magnetism and solar radiation. Proc. Nation. Acad. Sci., **2,** 24-27 (1916).

Measures of the electric and magnetic activity of the Sun and the Earth, and interrelations. Terr. Mag., **26,** 33-68 (1921). [The principal paper.]

Note regarding the "Earth-effect" on solar activity and relation with terrestrial magnetism. Terr. Mag., **26,** 113-115 (1921).

On measures of the Earth's magnetic and electric activity and correlations with solar activity. Bull. Nation. Res. Council, No. 17, 59-65 (1922).

Note on a simple measure of the Earth's daily magnetic activity. Trans. Rome Meeting, Internat. Geod. Geophys. Union, Sec. Terr. Mag. Electr., Bull. No. 3, 103-106 (1923).

Studies concerning the relations between the activity of the Sun and of the Earth's magnetism. (In collaboration with C. R. Duvall.) Terr. Mag., **30,** 191-213 (1925); **31,** 37-47, 97-101 (1926).

Magnetic Survey work—(1) Maryland, (2) United States, (3) Earth—(1) Two major and seven minor reports, 1897-1911, were published by the Maryland Geological Survey on the results of magnetic survey-work conducted by Bauer in Maryland, 1896-1899. The two major publications are:

First report upon magnetic work in Maryland, including history and objects of magnetic-surveys. Maryland Geol. Surv., **1**, 405-530 (1897). [Confined largely to discussion of the magnetic-declination results obtained by Bauer in Maryland in 1896.]

Second report on magnetic work in Maryland. Maryland Geol. Surv. **5**, 25-98 (1905). [Published separately in 1902. Contains discussion and tabulations of the results of the magnetic observations (declination, dip, and intensity) made in Maryland, 1896-1899.]

The minor reports deal chiefly with the magnetic declination in the different counties of Maryland.

(2) Publications dealing with the magnetic survey of the United States were issued by the United States Coast and Geodetic Survey, 1900-06, and contain results obtained during the period 1899-1906, while Bauer was chief of the Division of Terrestrial Magnetism in that organization. About 13 papers also appeared, chiefly in the Journal of Terrestrial Magnetism, dealing principally with magnetic variations and disturbances.

The magnetic work of the United States Coast and Geodetic Survey. Terr. Mag., **4**, 93-104 (1899); also App. 10, Rep. Supt. U. S. Coast Geod. Surv., 1898-1899, 939-952 (1900). [A general account of the work done previous to 1899, and the plan of work to be followed beginning with that year.]

Magnetic observatories of the United States Coast and Geodetic Survey in operation July 1, 1902 (in collaboration with J. A. Fleming). App. 5, Rep. Supt. U. S. Coast Geod. Surv., 1902, 301-331 (1903). Summarized in Terr. Mag., **8**, 11-29 (1903). [Contains description of the four magnetic observatories then existing: Cheltenham, Sitka, Honolulu, and Baldwin.]

United States magnetic declination tables and isogonic charts for 1902 and principal facts relating to the Earth's magnetism. Spec. Pub., U. S. Coast Geod. Surv., 406 pp. (1902, 1903). [The first 98 pages contain a treatise on early magnetic discoveries and the principal phenomena of terrestrial magnetism. These pages were also reprinted in pamphlet form under the title "Principal facts of the Earth's magnetism and methods of determining the true meridian of the magnetic declination" and reissued with slight alterations in 1909, 1914, and 1919. The latter part contains a compilation and discussion of the magnetic declination results and secular changes in the United States, with isogonic map for 1902.]

(3) The magnetic survey of the Earth constituted one of the major researches of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, particularly during the first two decades of its existence. The progress of this work was regularly reported in the Annual Reports of the Director of the Department of Terrestrial Magnetism, 1904-1925, reprinted from the respective year books of the Carnegie Institution of Washington. On the results of this survey, Bauer also contributed largely to Volumes I to V of the Researches of the Department of Terrestrial Magnetism (Publication No. 175 of the Carnegie Institution of Washington), and published various papers in the Journal of Terrestrial Magnetism, 1909-23, and the Scientific American, 1910-11, describing improvements of methods and instruments, especially for securing magnetic determinations of the required accuracy at sea.

Proposed magnetic survey of the North Pacific Ocean by the Carnegie Institution (in collaboration with G. W. Littlehales.) Terr. Mag., **9,** 163-166 (1904). Also Carnegie Inst., Year Book, **3,** 269-273 (1904).

Inauguration of the magnetic survey of the Pacific Ocean. Terr. Mag., **10,** 143-144 (1905). Also Science, **22,** 216-217 (Aug. 18, 1905).

The magentic survey of the North Pacific Ocean: Instruments, methods, and preliminary results. Terr. Mag., **11,** 65-92 (1906).

The work in the Pacific Ocean of the survey yacht *Galilee.* Nation. Geog. Mag., **18,** 601-611 (1907).

The magnetic survey yacht *Carnegie* and her work. Terr. Mag., **14,** 57-66 (1909).

Some problems of ocean magnetic work. Terr. Mag., **14,** 161-176 (1909).

The complete magnetic results of the first cruise of the *Carnegie,* 1909-1910. Terr. Mag., **15,** 57-82 (1910).

The magnetic survey of Australia. Terr. Mag., **16,** 215-217 (1911). [Announcement of inauguration of magnetic survey of Australia and general methods of work.]

New magnetic charts of the Indian Ocean. Proc. Amer. Phil. Soc., **51,** 123-124 (1912).

The C. I. W. deflector in use on the *Carnegie* for determining the magnetic horizontal intensity and the magnetic declination at sea (in collaboration with J. A. Fleming). Terr. Mag., **18,** 57-62 (1913).

The magnetic survey of the oceans. Geog. J., **42,** 517-530 (1913).

Regarding improvement of appliances for measurement of the Earth's magnetic elements by magnetic and electric methods. Terr. Mag., **19,** 1-18 (1914). [Progress report concerning especially the instrumental researches and appliances of the Department of Terrestrial Magnetism.]

General results of the magnetic survey of the Pacific Ocean (in collaboration with W. J. Peters). Terr. Mag., **20,** 95-103 (1915).

In addition to the above-mentioned publications, the magnetic declinations and chart-corrections obtained by the *Carnegie* were published, in collaboration with the commander of the vessel, in the JOURNAL OF TERRESTRIAL MAGNETISM promptly upon their receipt, thus making available the data for use by the various hydrographic services of the world.

Cosmical magnetism and electricity –A number of papers were published during 1913-24, containing summaries of preliminary studies bearing upon cosmic effects in terrestrial magnetism and electricity, possible planetary magnetic fields, and similarities in the magnetic fields of the Earth, atmosphere, and Sun.

Correlation between solar activity and atmospheric electricity, and annual variation of atmospheric electricity—The principal papers are:

Correlations between solar activity and atmospheric electricity. Terr. Mag., **29,** 23-32; 161-186 (1924).

Sunspots and annual variations of atmospheric electricity, with special reference to the *Carnegie* observations 1915-1921. Res. Dep. Terr. Mag., Carnegie Inst., Pub. No. 175, **5,** 359-424 (1926).

The chief conclusions reached in these studies on the basis of land- and ocean-data are: (1) To indicate with a high degree of probability that during the cycle 1913-22, the atmospheric potential-gradient, and its diurnal and annual variations, increased with increasing sunspottedness by at least 20 per cent of its mean value for the cycle between the years of minimum and maximum sunspottedness; (2) In general, over the oceans the atmospheric potential-gradient is, on the average, greater during the period October to March, than during the period April to September, when the Earth is farthest from the Sun, and since a similar

general conclusion was reached from land observations, there is a possibility that the annual variation of the potential gradient, like the diurnal variation, may have to be ascribed primarily to cosmic causes.

Earth currents—

Some results of recent earth-current observations and relations between solar activity, terrestrial magnetism, and atmospheric electricity. Terr. Mag., **27**, 1-30 (1922).

Thermodynamics—

The relation between "potential temperature" and "entropy." Phys. Rev., **26**, 177-183 (1908); Met. Zs., **25**, 79-82 (1908).

Miscellaneous

Bauer has also to his credit a number of papers on miscellaneous subjects, for example, magnetism, instruments, methods of research, etc. He is moreover the author of several popular essays and addresses before scientific and other societies. Some of the more important are as follows:

Hunting the magnetic pole. Van Norden Mag., **2**, 55-67 (1907).

The Earth's magnetism. Halley Lecture at the University of Oxford. Bedrock, **2**, 273-294 (1913). Reprinted with additions in Smithsonian Inst. Report, 195-212 (1913).

Our Earth a great magnet. J. Frank. Inst., **181**, 601-628 (1916).

Some of the chief problems in terrestrial magnetism and electricity. Proc. Nation. Acad. Sci., **6**, 572-580 (1920).

The most curious craft afloat. Nation. Geogr. Mag., **21**, 223-245 (1910).

The cruises of the *Carnegie*. World's Work, **39**, 280-301 (1920).

An account of Bauer's scientific writings would not be complete, unless mention were made of his contributions as an editor of scientific literature. This Journal was founded as "Terrestrial Magnetism" in 1896, its title including "Atmospheric Electricity" from 1899. He was its sole editor until 1927, and co-editor until his death. The part played by the Journal in the advancement of the study of terrestrial magnetism and electricity during the long period of his editorship has been an important one. While secretary and director of the Central Bureau, Section of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, 1919-27, he edited and published the first six bulletins of that Section.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

DAS RÄTSEL DER ERDMAGNETISCHEN SÄKULARVARIATION

Von Adolf Schmidt

Unser Wissen von der Säkularvariation des Erdmagnetismus ist von Louis A. Bauer nach zwei Richtungen bedeutsam erweitert worden. In seiner Berliner Inaugural-Dissertation[1] vom Jahre 1895 hat er für alle Orte, von denen schon damals längere Reihen von Deklinations-und Inklinationsbeobachtungen vorlagen, das Vektordiagramm der säkularen Aenderung der Kraftrichtung entworfen. Aus seinen Ergebnissen glaubte er schliessen zu dürfen, dass das Diagramm an allen Punkten der Erdoberfläche in demselben Sinne—von aussen gesehen in dem der Uhrzeigerbewegung—durchlaufen werde. In einer späteren Arbeit[2] wies er darauf hin, dass die älteren Berechnungen des erdmagnetischen Potentials für das magnetische Moment der Erde einen wesentlich höheren Wert ergeben haben, als die neueren, die auf den Karten von Neumayer beruhen. Er betrachtete die Momentabnahme als reell und stützte diese Ansicht durch eine auf den Beobachtungen an einer Anzahl von Observatorien beruhende Untersuchung. Inzwischen ist seine Annahme durch die Ergebnisse seiner Potentialberechnung für die Epoche 1922 völlig sicher gestellt worden, indem diese eine sogar noch stärkere weitere Abnahme ergab. Die Möglichkeit, dass es sich um eine stets in demselben Sinne fortschreitende Aenderung handeln könne, darf als ausgeschlossen gelten; die Annahme einer solchen würde schon für die jüngste geologische Vorzeit auf undenkbar hohe Momentwerte führen. Man wird vielmehr mit grosser Wahrscheinlichkeit annehmen dürfen, dass die Aenderung des Moments ebenso wie diejenige der Feldrichtung periodischer Natur sei, und dass die Säkularvariation eine einheitlich die ganze Erde erfassende Erscheinung darstelle. Gegen diese Auffassung, die sich bei der Vergleichung der Isogonensysteme für verschiedene Epochen fast zwingend aufdrängt, und die auch den Theorieen von A. Schuster und V. Carlheim-Gyllensköld zu grunde liegt, scheint zu sprechen, dass die Potentialberechnungen für die zwei Epochen 1842 und 1885 in allen Koeffizienten, nicht nur in denen der ersten Ordnungen, beträchtliche Unterschiede aufweisen. Um dem Bedenken zu begegnen, dass besonders die älteren Entwicklungen auf einem recht mangelhaften Material beruhen, und dass also jene Unterschiede vielleicht nur auf den Fehlern der Beobachtungsgrundlagen beruhen, liegt es nahe, das Potential ausschliesslich aus den Beobachtungen an Observatorien abzuleiten, was freilich wegen deren sehr ungünstigen Verteilung andere, aber für den vorliegenden Zweck weniger störende Fehler zur Folge hat. Einige von mir in dieser Richtung gemachte Versuche liessen eine umfassende Prüfung der Frage erwünscht erscheinen, die dann auf meine Veranlassung von J. Bartels durchgeführt wurde, der damit noch eine kritische Untersuchung der von Carlheim-Gyllensköld in seiner klassichen Arbeit erhaltenen Ergebnisse verband.[3] Bartels stellte als Schlussresultat

[1]Beiträge zur Kenntnis des Wesens der Säkularvariation des Erdmagnetismus, In.-Diss., Berlin (1895).

[2]Terr. Mag., **8**, 97-129 (1903); **9**, 173-186 (1904).

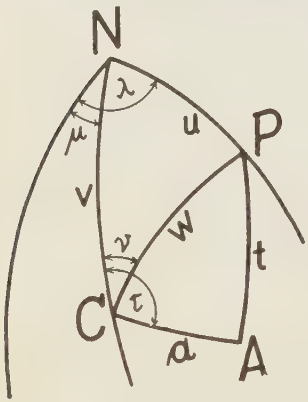
[3]Versuch einer analytischen Darstellung des Verlaufs der Säkular-Variation im Zeitraum 1902-1920. Archiv des Erdmagnetismus, Heft 5, 23-44 (1925).

seiner Prüfung fest (S. 36), dass die Darstellung der Säkularvariation an den benutzten 14 Stationen durch die 8 ersten Glieder der Kugelfunktionenreihe viel ungünstiger ist, als die des permanenten Feldes. Die Differenzen des beobachteten gegen das berechnete Feld erreichen bei jener fast die Hälfte, bei diesem kaum ein Zehntel des berechneten Feldes. (Man kann hierin, nebenbei bemerkt, auch ein Argument für die selbständige Bedeutung des Hauptgliedes des permanenten Feldes erblicken.)

Zu den grossen regionalen Ungleichmässigkeiten des Säkularfeldes kommen nun aber auch zeitliche Schwankungen von ähnlicher Grösse. Das lässt vermuten, dass es sich bei der Säkularvariation in der Hauptsache um einen einigermassen regelmässigen Vorgang handelt, dem wellenförmig fortschreitende sekundäre Schwankungen übergelagert sind.

Zur Erklärung hierfür bietet sich ungezwungen die Annahme eines magnetischen Erdkerns dar, der sich gegenüber der übrigen Erde langsam dreht, und dessen Magnetisierung zwar im ganzen gleichmässig, aber stellenweise gestört ist. Wie ich schon früher gelegentlich erwähnt habe (Zs. Geophysik, 4, 298, 1928), lässt sich auf dieser Vorstellung eine einigermassen befriedigende Erklärung besonders für die weit zurückreichenden Variationen gewinnen. Der Verlauf während der letzten hundert Jahre war dagegen weniger befriedigend darzustellen. Immerhin scheint mir das Ergebnis eine ausführlichere Wiedergabe zu verdienen, die im Folgenden um so eher ihre richtige Stelle hat, als sie sich fast ausschliesslich auf die zu Anfang erwähnten Feststellungen von L. A. Bauer stützt.

Von der geschilderten Annahme ausgehend denken wir uns das beobachtete, sogenannte beharrliche, aber im Laufe der Jahrhunderte langsam veränderliche erdmagnetische Gesamtfeld zusammengesetzt aus einem konstanten (im eigentlichen Sinne beharrlichen) Felde $\mathfrak{F}$ und einem andern, in sich gleichfalls festen, aber seine Lage stetig ändernden Felde $\mathfrak{S}$. Wir nehmen an, dass die Lageänderung in einer gleichförmigen Drehung um eine in der Erdrinde feste Achse besteht. $\mathfrak{S}$ besteht seinerseits aus zwei Teilen: dem Felde $\mathfrak{S}'$ des magnetischen Kerns und dem Felde $\mathfrak{S}''$ der von diesem induzierten subpermanenten Magnetisierung der Erdrinde. Eine Trennung des an der Erdoberfläche allein zu beobachtenden Feldes $\mathfrak{S}$ in diese beiden Bestandteile ist bis auf weiteres nicht möglich, aber auch nicht nötig, da sich $\mathfrak{S}$ von $\mathfrak{S}'$ nur in Intensität und Phase aber nicht seiner Form nach unterscheidet. Von den in $\mathfrak{S}'$ und $\mathfrak{S}''$ zu vermutenden Unregelmässigkeiten ist hierbei natürlich abzusehen.



In der Figur bezeichne N den geographischen Nordpol der Erde, und P einen beliebigen Punkt ihrer Oberfläche mit den sphärischen Koordinaten u, λ. Der als homogen magnetisiert und zur Erdkugel konzentrisch angenommene Kern drehe sich gleichförmig um eine Achse, die die

Oberfläche in dem festen Punkte C mit den Koordinaten v, μ trifft, und zwar sei C derjenige der beiden Schnittpunkte, von dem aus gesehen die Drehung im Sinne der Uhrzeigerbewegung geschieht. Das Nordende der magnetischen Achse des Kerns gehe im Augenblick T durch A und das Moment sei $(4\pi/3)\ R^3 m$. Der Zeitpunkt, zu dem A durch $C\ N$ oder dessen Verlängerung über N hinaus geht, werde T_0 genannt. Der die Lage der Achse kennzeichnende Winkel NCA ist dann $\tau = \text{const.}\ (T - T_0)$. Wir nehmen von vornherein die Dauer einer Umdrehung des Magnetkerns nach den Beobachtungen von London und Paris zu 480 Jahren an, so dass, wenn T in Jahren gemessen wird, const. = 0°.75 zu setzen ist.

Das Potential von $\mathfrak{S}$ ist $\triangle V = m \cos AP$. Man hat somit

$$\triangle V = m \cos a \cos w + m \sin a \sin w \cos (\tau - \nu)$$

Das von der Zeit unabhängige erste Glied darf hier ausser Acht bleiben, so dass mit $m \sin a = m'$

$$\begin{aligned}\triangle V &= m' \sin w \cos \nu \cos \tau + m' \sin w \sin \nu \sin \tau \\ &= m' (\sin v \cos u - \cos v \sin u \cos (\lambda - \mu)) \cos \tau + \\ &\quad m' \sin u \sin (\lambda - \mu) \sin \tau\end{aligned}$$

wird. Man gelangt hierzu auch unmittelbar, wenn man bedenkt, dass das Moment der homogenen Magnetisierung in zwei Komponenten zerlegt werden kann, von denen nur die zur Drehachse des Kerns senkrechte wirksam wird. Das kommt darauf hinaus, dass man von vornherein $a = 90°$ annimmt und $m \sin a$ durch m' ersetzt.

Für die in üblicher Weise definierten Feldkomponenten

$$\triangle X = \frac{\partial \triangle V}{\partial u}, \qquad \triangle Y = -\frac{1}{\sin u}\frac{\partial \triangle V}{\partial \lambda}$$

folgt hieraus

$$\begin{aligned}\triangle X &= -\ m' (\sin v \sin u + \cos v \cos u \cos (\lambda - \mu)) \cos \tau + \\ &\quad m' \sin u \sin (\lambda - \mu) \sin \tau \\ \triangle Y &= -m' \cos v \sin (\lambda - \mu) \cos \tau - m' \cos (\lambda - \mu) \sin \tau\end{aligned}$$

während $\triangle Z = -\ 2 \triangle V$ ist.

Wenn man die, wie erwähnt, nur scheinbar spezialisierte Darstellung (a = 90°) benutzt, lässt sich die Wirkung an jedem einzelnen Orte unmittelbar auch ohne Rechnung ersehen. A und der negative südliche Gegenpol A' bewegen sich dann auf einem grössten Kugelkreise. Die vertikale Komponente in P ist $2\ m' \cos t$; sie hat ihr Maximum, wenn $A\ P$ senkrecht auf dem Bahnkreise steht. Die horizontale Komponente hat dann ihr Minimum; sie ist gleich $m' \sin t$ und fällt in die Verlängerung von $A\ P$. Beim Fortschreiten von A in seiner Bahn dreht sie sich also, eine ellipsenähnliche Figur überstreichend, um P, und zwar in demselben oder entgegengesetzten Sinne wie A, je nachdem ob P auf derselben Halbkugel wie C liegt oder nicht. Fällt P mit C zusammen, so wird die Ellipse zum Kreise; sie verschmälert sich in dem Masse, in dem P dem Bahnkreise näher kommt.

Weniger einfach zu übersehen, als dieses XY-Diagramm, ist das $I\ D$-Diagramm der Bauer'schen S-Kurven, weil hierbei die Zusammensetzung der beiden Felder $\mathfrak{F}$ und $\mathfrak{S}$ in Betracht kommt, deren Winkel von Ort zu Ort wechselt. Man sieht aber ohne weiteres ein, dass es dem XY-

Diagramm um so ähnlicher wird, je grösser die Inklination (absolut genommen) wird, mit andern Worten, je weiter P vom Aequator entfernt ist. Da alle wichtigen von Bauer benutzten Stationen in mittleren Breiten liegen, darf man die oben durchgeführten Ueberlegungen mit einiger Annäherung auch bei seinen S-Kurven als zutreffend ansehen. Man sieht dann, dass diese dem geschilderten Bilde in den Hauptzügen entsprechen, wenn man C als zwischen London-Paris und Capstadt gelegen annimmt, so dass der Bahnkreis der Säkularpole ungefähr mit dem Meridian von 90° und 270° zusammenfällt. An jenen beiden Orten nähert sich die S-Kurve einem Kreise, während in Boston und Peking, die dem Bahnkreise näher sind, ihre Verschmälerung senkrecht zu diesem angedeutet ist.

Ein sicheres Urteil kann indessen nur die Vergleichung des beobachteten mit dem theoretischen ID-Diagramm gewähren. Sind dessen Koordinaten, in Winkelgraden ausgedrückt, ξ (+ nach oben) und η (+ nach rechts), so hat man mit $\epsilon = 180°/\pi = 57°.3$ genähert

$$\xi = -\epsilon \triangle I/F = \epsilon (\sin I \triangle X - \cos I \triangle Z)/F, \quad \eta = \epsilon \triangle D/F \cos I$$

Nun ist, wenn von der schiefen Achsenlage von $\mathfrak{F}$ (mit dem Südpol in N) abgesehen wird, was bei dieser nur zur ersten Orientierung dienenden Rechnung geschehen darf

$$X = M \sin u, \quad Z = 2\ M \cos u, \quad F = M\ e = M\sqrt{1 + 3 \cos u^2},$$
$$\sin I = 2 \cos u/e, \quad \cos I = \sin u/e$$

Hieraus folgt

$$\xi = \epsilon (2 \cos u \triangle X - \sin u \triangle Z)/M\, e^2, \quad \triangle D = \epsilon \triangle Y/M \sin u_1$$

$$\xi = \epsilon \left(2 \cos u \frac{\partial \triangle V}{\partial u} + 2 \sin u \triangle V\right)/M\, e^2 = \frac{2\epsilon}{M\, e^2}\phi\ (\triangle V)$$

Beachtet man, dass $\phi\ (\sin u) = 1$ und $\phi\ (\cos u) = 0$ ist, so liest man aus dem früher für $\triangle V$ gefundenen Ausdruck unmittelbar ab

$$\xi = \frac{2\,\epsilon}{e^2}\,\frac{m'}{M}(-\cos v \cos (\lambda - \mu) \cos \tau + \sin (\lambda - \mu) \sin \tau)$$

und

$$\eta = -\frac{\epsilon}{\sin u}\,\frac{m'}{M}(\cos v \sin (\lambda - \mu) \cos \tau + \cos (\lambda - \mu) \sin \tau)$$

Die allgemeine Diskussion dieser Formeln bietet manches Interessante, muss aber aus Raummangel hier unterbleiben. Nur ein Punkt sei erwähnt. Berechnet man den Inhalt der von einer ID-Kurve eingeschlossenen Fläche, so findet man, dass er überall auf der Kugel dasselbe Vorzeichen hat. Das bedeutet, dass diese Fläche überall in demselben Sinne umfahren wird. Damit findet der entsprechende von Bauer in glücklicher Intuition aus seinen an sich dazu kaum ausreichenden Ergebnissen gezogene Schluss eine eindrucksvolle Bestätigung. Für ihre Anwendung auf die vorliegenden Beobachtungen kommen zunächst nur diejenigen Orte in Betracht, deren S-Kurven sich ohne zu grosse Willkür zum vollen Umlauf ergänzen lassen: das am besten in ein Mittel zusammenzufassende Stationspaar London-Paris ($u = 40°$, $e^2 = 2.76$) und die Station Capstadt ($u = 124°$, $e^2 = 1.94$).

Ihre von Bauer aus den Beobachtungen abgeleiteten S-Kurven lassen sich mit grosser Annäherung durch die ausgleichenden Formeln

$$\text{London-Paris:} \quad \xi = 4°.6 \cos \tau, \quad \eta = 16°.5 \sin \tau$$
$$\text{Captstadt:} \quad \xi = 8° \cos \tau, \quad \eta = 15° \sin \tau$$

darstellen, wobei T_0 zu 1700 angenommen ist, zu welchem Zeitpunkte an beiden Orten das dem Werte $\tau = 0$ entsprechende Maximum von I eintrat. Bei der Vergleichung dieser Ausdrücke mit den allgemeinen Formeln wird man in diesen für beide Orte unbedenklich $(\lambda - \mu) = 0$ setzen dürfen, so dass i. M. $\mu = 10°$ folgt.

Hieraus ergibt sich

$$\text{London-Paris:} \; m/M = 0.174, \; \cos v = 0.637, \quad \pm v = 50°.4$$
$$\text{Capstadt:} \quad m/M = 0.217, \; \cos v = 0.624, \quad \pm v = 51°.4$$

Das Vorzeichen von $\cos v$ ergibt sich daraus, dass ξ für $v = 0$ negativ ist. (Das Ergebnis zeigt nebenbei, dass die genäherte Identifizierung der XY-Diagramme mit den ID-Diagrammen, die auf einen nahe bei 90° liegenden Wert von v schliessen liess, recht unzuverlässig ist.)

Im Mittel, bei dem dem ersten Wert das doppelte Gewicht zu geben ist, hat man also

$$m'/M = m \sin a/M = 0.19, \quad \pm v = 51°, \quad \mu = 10°$$

Die Uebereinstimmung der Ergebnisse der beiden Stationen ist im Hinblick auf die weitgehenden Vereinfachungen in der theoretischen Entwicklung und auf die geringe Genauigkeit der nur näherungsweise geschätzten Beobachtungsdaten so befriedigend, dass man sie z. T. wohl dem Zufall zuschreiben muss.

Es muss hervorgehoben werden, dass die Annahme $T_0 = 1700$ und $(\lambda - \mu) = 0$ zwar durch den Anblick der beiden Säkularkurven nahegelegt und besonders einfach, aber doch willkürlich ist. Den für v und m/M sowie für τ und μ erhaltenen Werten kommt daher nur die Bedeutung einer formell möglichen Lösung zu. Zu ihrer eindeutigen Bestimmung reichen die hier verwendeten Daten nicht aus. Der Versuch, durch Hinzunahme weiterer Daten die (unter der Voraussetzung der Richtigkeit der Grundhypothesen) wahren Werte dieser Grössen zu ermitteln, muss wegen der hier gebotenen Raumbeschränkung einer späteren Gelegenheit vorbehalten bleiben. Schon jetzt aber kann gesagt werden:

> Der säkulare Gang der erdmagnetischen Kraftrichtung in London, Paris und Capstadt steht in grossen Zügen im Einklang mit der Hypothese, dass die Säkularvariation durch die gleichmässige, in einer Periode von 480 Jahren erfolgende Umdrehung eines homogen magnetisierten Erdkerns verursacht werde.

So eindrucksvoll diese Feststellung wirkt and für die erwähnte Hypothese spricht, so muss doch auch die Variation der Feldstärke, die in erster Linie von der Aenderung des Moments abhängt, beachtet werden, und dabei tritt das anscheinend gelöste Rätsel erneut in die Erscheinung. Beschränken wir die Betrachtung wieder auf das zonale Glied, so wird das Potential (wie der Kürze halber schon bisher immer statt Potential, dividiert durch Erdradius, gesagt worden ist) der Gesamtmagnetisierung gleich $(-M + m' \sin v \cos \tau) \cos u$.

Für $\tau = 0$, d.h. um das Jahr 1700, hat hiernach das Moment, d.i. der Absolutwert des Faktors von cos u, sein Maximum oder sein Minimum, je nachdem ob v negativ oder positiv ist.

Nun haben die bisherigen Potentialberechnungen für diesen in der Einheit 10γ gemessenen Faktor (g_1^0 nach der üblichen Bezeichnung) die folgenden Werte ergeben:[4]

Epoche: 1842, − 3217; 1885, −3173; 1922, −3047

Zusammenfassend erhält man hieraus für das Moment den Wert

$$2867 - 350 \cos (\tau + 74°) = 2867 - 350 \cos 0°.75 \, (T - 1600)$$

Als Epoche des Minimums ergibt sich hieraus die Zeit um 1600, als die des Maximums die Zeit um 1840. Der Durchgang durch den Mittelwert gegen 1720 fällt danach also nahezu auf die Zeit, zu der nach den S-Kurven gerade ein Extrem erreicht wurde. Der Phasenunterschied der beiden Wertverläufe beträgt, wenn man v positiv annimmt, 75° (100 Jahre), bei negativem v sogar 105° (140 Jahre), weshalb es sich rechtfertigen liesse, dem positiven Wert von v den Vorzug zu geben. Was die Grösse der Schwankung betrifft, so führen beide Ableitungen zu nicht gar zu verschiedenen Werten, dem Faktor 0.19 sin v, d.i. 0.15 bei der einen steht bei der andern 350/2867 d.i. 0.12 gegenüber. Da der ersten wohl ein grösseres Gewicht zu geben ist, wäre ausgleichend und abrundend zu setzen

$$g_1^0 = -2900 \, (1 - 0.14 \cos \tau) = -2900 + 400 \cos 0°.75 \, (T - 1700)$$

Der Widerspruch zwischen den beiden Darstellungen ist aber zu stark, als dass er durch eine Ausgleichung beseitigt werden könnte, und damit bleibt die Berechtigung der zugrunde gelegten Hypothese fraglich. Damit entsteht die Aufgabe, die vorliegende Untersuchung in strengerer Weise unter Benutzung alles geeigneten bis zur Gegenwart reichenden Beobachtungsmaterials zu wiederholen. Erst, wenn dies geschehen ist, ohne dass der Widerspruch geschwunden ist, wird es an der Zeit sein auf weitere Erklärungsmöglichkeiten zu sinnen.

Die alsdann gewonnene (und mit einiger Vorsicht auch schon die hier erhaltene vorläufige) Darstellung des ausgeglichenen säkularen Ganges wird, auch wenn sie nur formalen Wert haben sollte, die beste Grundlage für die Untersuchung der lokalen und regionalen Anomalieen dieses Ganges bilden. Die Feststellung dieser Anomalieen, die jetzt und für lange Zeit als wichtigste Beobachtungsaufgabe zu gelten hat,[5] wird ihrerseits dazu beitragen, die empirische Grundlage zu sichern, auf der eine immer vollkommenere Theorie der allgemeinen Säkularvariation zu errichten ist.

[4]Zusammengestellt von L. A. Bauer in Terr. Mag., **28**, 15 (1923).

[5]Vergleiche die Ausführungen von J. A. Fleming und H. W. Fisk, On the distribution of permanent repeat-stations. Zs. Geophysik, **7**, 74-80 (1931).

Lützowstrasse 1,
Gotha, Deutschland

SECULAR CHANGE OF THE EARTH'S MAGNETISM

By Daniel L. Hazard

It is appropriate at this time to review briefly the development of our knowledge of the secular change of the Earth's magnetism, particularly in the United States, in view of Bauer's lifelong interest in the subject and his noteworthy contributions to it.

Henry Gellibrand, professor of mathematics at Gresham College, England, is credited with the discovery of the fact that the magnetism of the Earth changes with time. On June 12, 1634, he made a careful determination of the magnetic declination at Diepford, about three miles southwest of London Bridge, and got a value of 4° 06′ east, where Borough and Norman had found 11° 15′ east in 1580. He announced his discovery in "A Discourse Mathematicall on the Variation of the Magneticall Needle, together with its Admirable Diminution Lately Discovered," published in 1635.

The importance of this discovery was at once recognized and from that time to the present day many geophysicists or "natural philosophers," as they would have been called in Gellibrand's day, have studied the phenomenon from many angles in an effort to determine its nature and cause. The earlier investigations were necessarily very limited in scope because of the small number of places at which repeated observations had been made, but they served to bring together the available results not only at repeat stations but also at all places where observations had been made and preserve them for later use.

Even now the period of time covered by magnetic observations is extremely short when compared with the geologic ages during which it may be assumed that the magnetic field of the Earth has been in existence. The first absolute determination of the intensity of the field was made only about 100 years ago, Norman's first dip observations were made in 1576, and declination data go back as much as 400 years for only a few localities.

Various attempts have been made to obtain results for earlier years from other sources. The early charts of the Mediterranean coasts of the 14th and 15th centuries were oriented by compass, as the fact that the compass does not point true north was not known at that time. By measuring the angle through which Bianca's chart of 1436 had to be turned (about Rome as a center) in order that the places would fall in their proper geographical relations, Bauer concluded that the magnetic declination at Rome was about 5° east not long before the date of the chart.

Efforts have been made to obtain values of dip from old Roman pottery in which have been found evidence of magnetic polarity, on the assumption that they acquired magnetism by induction at the time of baking and that they stood in a horizontal position in the oven, but the results are conflicting and hence of doubtful value.

Mercanton and others have made studies of the remanent magnetism of eruptive rocks in different localities, both for early historical and for geological times, from which estimates of the declination and dip at those times have been made, assuming that the magnetism was acquired at the time the rocks cooled and that they have maintained their orientation since then. Mercanton found indications that there has been a reversal of the polarity of the Earth's magnetism since geologic times,

but more extended investigations must be made before definite conclusions can be reached.

Van Bemmelen and Fritsche added somewhat to the limited knowledge of the secular change prior to 1800 derived from repeated observations in the same place by preparing magnetic dip and declination charts for different epochs 50 years or so apart, each based on the results of observations made within a few years of a selected epoch. In this way a rough outline of the change between different epochs was obtained for the portion of the Earth covered by the observations.

In the United States the study of the subject was stimulated by the practical needs of the land-surveyors. Most of the early land-surveys were made by compass, and in order to retrace lost boundaries in later years a knowledge of the change of declination was called for.

When Schott became chief of the computing division of the United States Coast Survey in 1855 he applied himself energetically to the problem of supplying this information. He made a collection of all available results of magnetic observations in the United States and adjacent regions. Observations were made by the Coast Survey at a considerable number of places for which early results had been found and arrangements were made for future systematic repeat-observations at selected stations at suitable intervals. Considerable information regarding the change of declination was obtained from local surveyors, based on their experiences in retracing well-defined boundaries of old surveys. From Halley's Tabula Nautica and Isogonic Chart for 1700 he was able to derive rough values of declination for that date for places along the Atlantic Coast where observations had been made later. From a discussion of observations along the Pacific Coast by Spanish navigators between 1775 and 1800 he deduced approximate values of declination for that region for the epoch 1783.

From this collection of results it was possible to select a considerable number of places where observations had been made several times. The discussion of the secular change of declination at London, Rome, and Paris, for which the longest series of observations are available, had shown that the rate of change is not uniform and that it does not go on indefinitely in one direction. At London, for instance, an easterly extreme was reached in 1590 and a westerly extreme in 1810. Schott found that the observations at these places could be represented with a fair degree of approximation by a simple periodic function, differing somewhat in period and amplitude at different places. He decided therefore to base his discussion of secular-change data in the United States on the supposition that they could be represented in the same way.

For each place he first obtained graphically an approximate value of the period and then by the method of least-squares computed the amplitude and phase-angle. He then repeated the computations with periods greater and less than the first by small amounts. That period was adopted which gave best agreement between observed and computed values. The places having the longer series of observations were treated first; and these were used to fix the periods for places in the same region for which the observations covered a shorter period of time.

For a few places where observations had been made at shorter intervals, he was able to represent them more closely by introducing a second term of shorter period in the formula. Schott repeatedly pointed out that these were simple, empirical formulas intended primarily for interpolating between the observed values and that they could not

safely be used to extrapolate much beyond the limits of the period covered by the observations, and as later observations became available he revised his computations.

Schott also applied his methods in modified form in discussing the secular change of dip and horizontal intensity in the United States, but for only a few places was the period covered by observations long enough to derive a periodic formula.

Littlehales extended Schott's investigations to places scattered all over the globe for which he was able to collect an extended series of observations of declination or dip.

Bauer served in the United States Coast and Geodetic Survey under Schott from 1887 to 1892, and from him acquired that keen interest in the study of the Earth's magnetism which led him to adopt it as his life work. Quite naturally, the secular change was one of the first subjects of his investigations, as indicated by his paper "On the secular motion of a free magnetic needle," presented before the American Association for the Advancement of Science in 1892, and his inaugural thesis for the Doctor's degree at the University of Berlin in 1895: "Beiträge zur Kenntnis des Wesens der säcular Variation des Erdmagnetismus."

Kupffer, Quetelet, and others in Europe, and Schott in the United States had recognized that the true nature of the secular change of the Earth's magnetism could not be derived from a study of the variations of the magnetic elements separately, and had made some attempts to treat the changes of declination and dip as a single phenomenon. Because of the periodic character of the secular change it seemed possible that it might be due to a similar change in the direction of the magnetic axis of the Earth.

Bauer developed a method of representing graphically the secular motion of the north end of a freely suspended magnetic needle, on the basis of observed changes of declination and dip at a station, and applied it to many places for which available results extended over a long period. He found that for most places, in the southern as well as in the northern hemisphere, the north end of the needle, as viewed by an observer at the point of suspension, moved in the direction of the hands of a watch. For the stations having the longest series of observations (London, Rome, Paris) the motion is in the form of an oval, though at no station has the oval been completed.

An investigation of the secular motion of the magnetic axis of the Earth followed naturally after these studies of the motion of a freely suspended needle. Bauer attacked the problem on the basis of values of declination and dip scaled from existing magnetic charts for different epochs, by a mathematical analysis of the Earth's magnetic field according to the method developed by Gauss and Schmidt. The results obtained in this way indicated a considerable motion of the magnetic axis during the period covered by the observations, but they differed materially from the results obtained by Van Bemmelen by a different method, using declination charts alone. A critical examination of the computations indicated that the results were probably affected by the fact that different portions of the Earth's surface were covered by the available data for different epochs and that it was therefore not safe to draw conclusions from the results.

In 1903 Bauer compared the various values of the Earth's magnetic moment which had been computed for different epochs from 1829 to 1885 by different investigators and found that apparently there had been

a decrease of 1.6 per cent between 1838 and 1884. He realized, however, that these computations were based upon incomplete and unhomogeneous data and that in order to determine the magnetic field of the whole Earth with accuracy many more observations would be required.

Fortunately he was able at about that time to bring about the establishment of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and to direct its energies toward the completion of a magnetic survey of the Earth, with particular attention to the ocean-areas.

In 1922, with the wealth of additional material which had been accumulated in the meantime, he recomputed the value of the Earth's magnetic moment and found a further diminution from the earlier values, making a total decrease of about five per cent in 80 years.

These investigations of Bauer and others showed that little additional knowledge of the secular change could be gained from a further study of the older observations; that only from more homogeneous results could definite conclusions be drawn. With the marked increase in activity in the study of the Earth's magnetism since the beginning of this century, the prime importance of adequate observations for keeping track of the secular change has been recognized, and provision has been made in many countries for repetitions of magnetic surveys or for the occupation of selected repeat-stations to supplement the more detailed information furnished by the continuous records of magnetic observatories. In the United States, for example, repeat-stations scattered all over the country have been occupied at intervals of about five years. At the time of her destruction the *Carnegie* was on a cruise designed to determine over the ocean-areas the change of the Earth's magnetism since previous cruises of the *Carnegie* and *Galilee*.

With the accumulation of more accurate results for identical stations at shorter intervals, it became evident that no simple empirical formula would give a satisfactory representation of the observed changes, that in addition to the broad swing of long period, with definite reversals of the direction of motion, there are variations of shorter period and smaller amplitude, with points of inflection and subsidiary maxima and minima.

There has resulted a change in the method of dealing with the problem. Instead of attempting a further analysis of results at individual stations covering a long period of years, studies are made of the change for selected intervals of time (five or ten years or the interval between two magnetic surveys) for a large area by drawing lines of equal annual-change for the interval, the so-called isopors. Fisk has been giving attention to the change in the relative position of the isopors for successive decades in certain regions and has brought out some very suggestive features. When it becomes possible to draw the isopors for the major portion of the Earth for several decades, we may expect more definite conclusions regarding the secular change of the Earth's magnetism as a whole. To attain this end it is essential to have repeated observations at suitable intervals at a sufficient number of stations well distributed over the Earth, and especially to provide in some way for continuance of the work at sea, which had been carried out so admirably on the *Carnegie*.

United States Coast and Geodetic Survey,
Washington, D. C.

THE UNSYMMETRICAL DISTRIBUTION OF MAGNETIC SECULAR VARIATION

By Harlan W. Fisk

In his paper announcing the results of his analysis of the Earth's magnetic field for 1922, Bauer[1] stated certain conclusions regarding secular variation which it is interesting to consider at the present time, in view of the more extended knowledge we now have of that phenomenon than was available when that paper was written. One of these conclusions is that "it must be recognized that the magnetic secular-variation system is as complex as the Earth's total magnetic system existing at any one time, and that in addition to changes in the direction of magnetization with the lapse of time, there is also a change in the average equivalent intensity of magnetization."

That the secular-variation system is even more complex than was then supposed by Bauer is made evident by reference to the series of isoporic charts (charts showing lines of equal annual change)[2] of the elements recently prepared by the writer as a preliminary picture of the distribution of secular variation, subject to elaboration as data accumulate. These charts show that a large portion of the total secular change of any of the magnetic elements is concentrated within a few restricted areas, and that the centers of these areas (or isoporic foci) are surrounded by concentric ovals which are densely crowded near the centers, and are more openly arranged elsewhere. If we plot all these foci for the several elements on a single chart, and represent them by heavy shaded circles, we have the arrangement shown in Figure 1. The lighter unshaded circles represent centers of moderate secular-change activity.

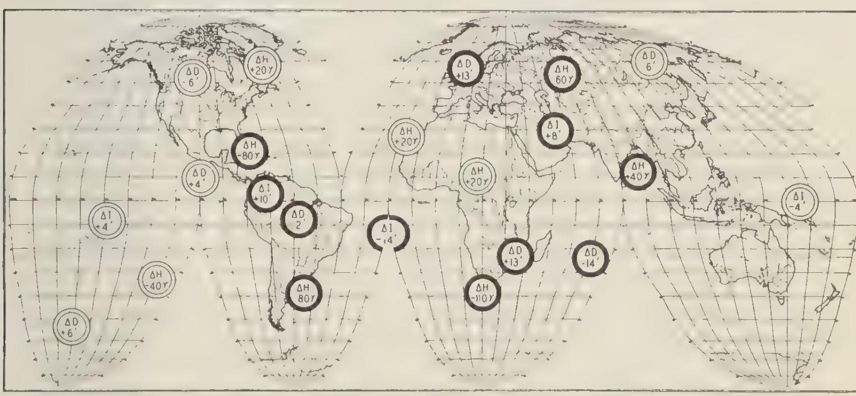


Fig. 1—Distribution of foci of greatest annual change of the magnetic elements

It has been elsewhere[3] pointed out that these very active centers are grouped roughly in one hemisphere, that lying between the meridians 90° east and 90° west, respectively, of Greenwich. This concentration is undoubtedly significant, and is probably connected in some real but at present unknown way with some phenomenon of the Earth's interior,

[1] Terr. Mag., **28**, 1-28 (1923).

[2] H. W. Fisk, Regional distribution of magnetic secular variation over the Earth's surface. Trans. Amer. Geophys. Union, 11th annual meeting, 215-223 (1930). Isopors and isoporic movements. Union. Geod. Geophys. Internat., Sect. Mag. Elect. Terr., Bull. No. 8, 280-292 (1931).

[3] J. A. Fleming, Time-changes in the Earth's magnetic field. Sci. Mon., **39**, 499-530 (1932).

perhaps related to crustal movements or subcrustal adjustments which are more active in the hemisphere containing the greatest land-masses than in the opposite one. If there are correlative or compensating changes such as one would expect to find if an alteration in the magnitude or the direction of the entire system of forces which give rise to the Earth's magnetic field were alone responsible for the phenomenon of secular variation, they are not immediately apparent. It is natural to conclude therefore that geophysical changes may and do occur in restricted portions of the Earth's interior which in turn produce changes in the magnetic field near those portions quite independent of changes occurring elsewhere.

While the regional and unsymmetrical character of secular-change activity is best shown graphically by means of the isoporic charts it is interesting and instructive to derive some quantitative measures of the irregularity by means of the charts themselves. Unfortunately the total-intensity isoporic chart though naturally the one to be used for the purpose could not be drawn with the requisite accuracy since it was of necessity compiled from data scaled from horizontal-intensity and inclination charts and the corresponding isoporic charts. The magnification of the inevitable inaccuracies of charts and scalings would introduce errors so great as to destroy the usefulness of such conclusions as might be derived. The same might be said of the vertical-intensity chart in its present form. However an examination of the distribution of the secular changes in the horizontal component alone are of interest and significance.

A striking feature of the H-isoporic chart is the overwhelming predominance of the negative annual changes of that element. An examination of available secular-variation data reveals no considerable area in the southern hemisphere where H is increasing at the present time. An isoporic chart of Latin America referred to the epoch 1915[4] showed an area along the equatorial portion of South America where the value of the horizontal component was increasing moderately. Recent observations indicate that the changes over all that region are now negative. Even the small area near the mouth of the Amazon shown on Figure 2, prepared before the latest observations were available, has now become an area of negative change. An area of increasing horizontal intensity appears in the East Indies and the Indian Ocean,[5] whose exact extent is not known as there are few observations in that region, but it cannot be large.

An approximate but useful measure of the predominance of the negative over the positive annual changes in H was derived in the following manner: Along parallels of latitude 10° apart from 70° north to 60° south, values of the annual change ($\triangle H$) were scaled from the H-isoporic chart at 20-degree intervals beginning at the Greenwich meridian. It was then assumed that each scaled value is the average annual-change over a quadrilateral area extending 10° in latitude and 20° in longitude, of which the point where the scaling was made was the center. The assumption though not strictly accurate is sufficiently so for the present purpose. Thus the spherical segment under consideration lying between 75° north and 65° south was divided into zones of equal width and varying area, and each zone was divided into 18 equal

[4] H. W. Fisk, Preliminary lines of equal annual change of the magnetic elements in 1915, for Latin America and adjacent waters. Terr. Mag., **29**, 139-148 (1924).

[5] H. W. Fisk, Secular variation of magnetic intensity and its accelerations in Pacific countries. Proc. Fourth Pacific Sci. Cong., Java, 1929, **2**, 517-530 (1930).

elementary quadrangles. The entire segment contains 93.6 per cent of the whole Earth's surface. By simple summation with suitable weighting for unequal areas of zones, it is easily found that the horizontal component is increasing over but 21 per cent of the segment and decreasing over the remaining 79 per cent, a proportion which would not

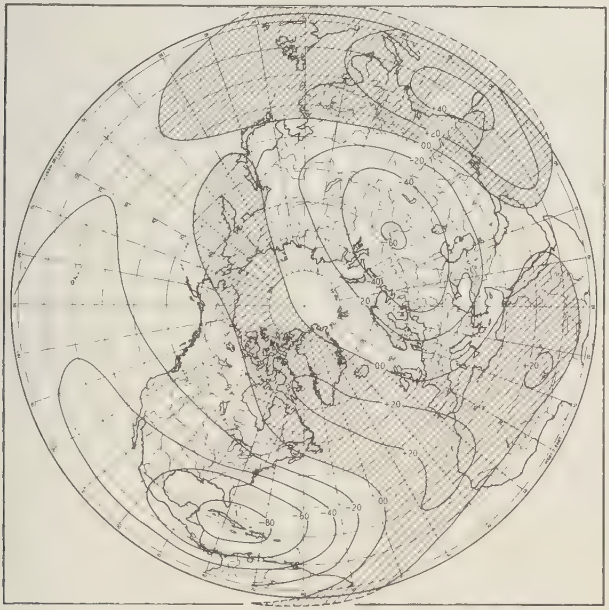


FIG. 2—Northern hemisphere showing areas having increasing horizontal intensity

be substantially altered were the whole sphere included. Rather more than nine-tenths of that 21 per cent lies north of the equator.

Not only is the area having negative annual-change much greater than that having positive annual-change, but the magnitude of the negative changes is much greater than that of the positive. When only the area having the positive annual-change is considered, the average change is +12.9 gammas with a moderate maximum of +40 gammas in the vicinity of the Bay of Bengal. Considering only the area having negative annual-change in the same way, the average is −33 gammas with maxima of −115 gammas near Cape Town, −85 gammas in the West Indies, −80 gammas in central Siberia, and −60 gammas in Patagonia. The preponderance of negative over the positive annual-changes is obvious, the average for the entire segment between 75° north and 65° south being −23.4 gammas.

By scaling from the United States Hydrographic Office chart of lines of equal horizontal intensity, the value of H for each point for which the $\triangle H$ was taken from the isoporic chart, the corresponding values of $\triangle H/H$ were found and are rather better for our purpose than the absolute values of the annual change expressed in gammas, though as it turns out there is no great difference in the relation between the average positive and the average negative annual-change when converted from absolute to percentage units; thus considering only the 21 per cent of

the segment where the change is positive, the average value of the ratio $\triangle H/H$ is $+0.00060$; over the 79 per cent where the change is negative the average value of $\triangle H/H$ is -0.00156. The average value of $\triangle H/H$ for the entire segment of the Earth's surface (75° north to 65° south) is -0.00111, or the horizontal component is diminishing at the average annual rate of one part in 900, when reckoned by the foregoing simple approximate method. It is interesting to compare this result with the conclusion reached by Bauer in the article to which reference was made in the first paragraph above, that the equivalent magnetization of the Earth has been diminishing during the period 1842 to 1922 at the average annual rate of one part in 1500, and further that "it would seem to be fairly well established now that both the horizontal and the equatorial components of the Earth's magnetic moment have been decreasing during the past sixty years; between 1885 and 1922 the annual decrease of both components has been as much as one-tenth of one per cent." Although the accuracy of the preliminary isoporic charts now available is insufficient to make it practicable to treat other components in the same manner, the general conclusion reached above by considering the horizontal component alone is in fair accord with that obtained from the more elaborate analysis. It should be borne in mind also that in making his deductions, Bauer compared his results with those of earlier investigators who were handicapped by the meagerness of the data then available.

Figure 3 represents the longitudinal distribution of $\triangle H/H$ around the Earth between the limiting parallels; the lower curve represents the average positive values of $\triangle H/H$ in each lune between the meridians spaced at 20-degree intervals found by summing with appropriate weights the values corresponding to each of the elementary quadrangles in the several lunes, while the upper curve represents the numerical magnitude of the average negative values taken in the same way; the shaded area between the curves is then the measure of the excess of the negative over the positive annual-change. The moderate rates of annual change over the Pacific as compared with those over the Atlantic and adjoining continental areas is clearly shown.

In Figure 4 the latitudinal distribution is shown in the same way. In this figure the positive annual-changes vanish and the curve merges with the zero-line a short distance south of the equator. There are two maxima on this positive curve when expressed as a ratio, $\triangle H/H$,

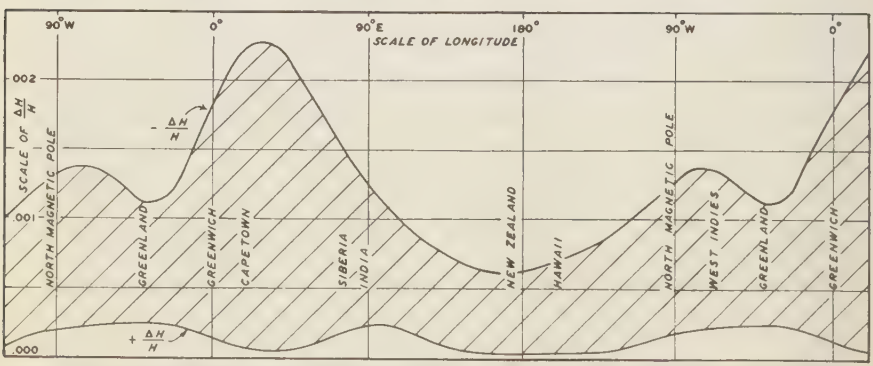


FIG. 3—Longitudinal distribution of proportion of annual change ($\Delta H/H$) of horizontal intensity

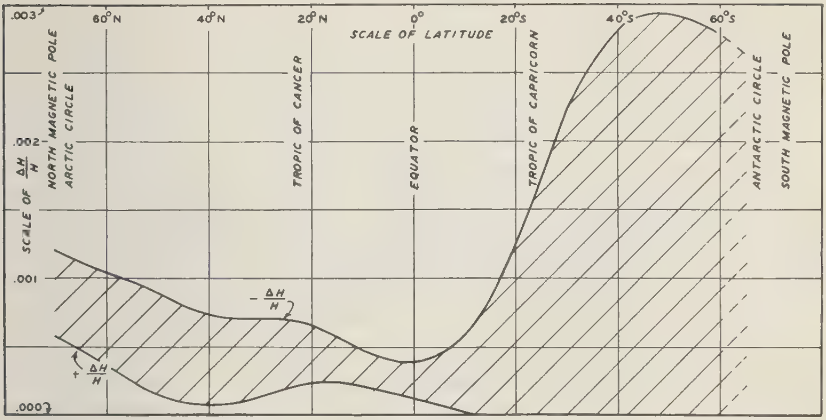


FIG. 4—Latitudinal distribution of proportion of annual change ($\Delta H/H$) of horizontal intensity

one near the north magnetic pole where the magnitude of H, the denominator, becomes very small, and the other in the latitude of India where the absolute annual change ($\triangle H$ expressed in gammas) is a maximum. The large average values of $-\triangle H/H$ in the southern hemisphere present a striking feature. This remarkable distribution with the large ratio of decrease of the horizontal component in the southern hemisphere and the positive increase limited to localities in the northern hemisphere presents an interesting subject for speculation since it seems to imply a displacement of the whole system of magnetizing forces toward the north.

The supposition has been made[1] that secular-change activity was in some way related to the distribution of land and water areas, the greater activity being associated with the hemisphere containing the largest proportion of land. This supposition is not supported by the picture of the latitudinal distribution of $\triangle H/H$ presented by Figure 4, since the greatest land area lies in the northern hemisphere where the total activity as represented by this component is smaller than in the southern or water hemisphere. However when the longitudinal distribution of $\triangle H/H$ is compared with the distribution of land taken in the same way, the suggestive correlation shown in Figure 5 is found. The heavy line shows the average annual-change with respect to longitude in which the positive and negative changes were added without regard to sign; the lighter line shows the relative land areas as measured by a planimeter on the equal-area map, of course neglecting the smaller islands, while the dotted line gives an approximate measure of the secular-change activity, found from the declination, inclination, and horizontal-intensity isoporic charts by estimating the relative density of the lines in each of the elementary areas. The correspondence of the curves of land distribution and the relative changes in horizontal intensity may be fortuitous, but it is clear that there is a pronounced difference in the general character of the changes taking place on the opposite sides of the Earth.

While it is customary to refer to all year-to-year changes in the magnetic elements as *secular variation*, a consideration of the regional and

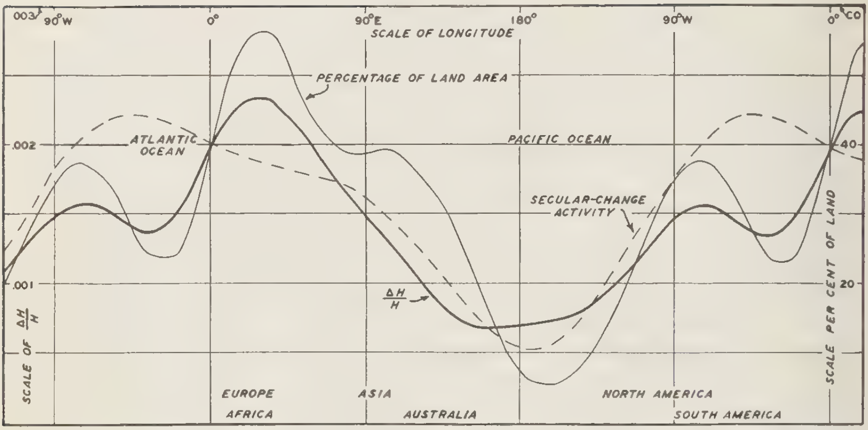


FIG. 5—Variation with longitude of $\Delta H/H$ (annual change averaged without regard to sign), of the distribution of the proportion of land and water areas, and of secular-change activity approximately determined by the density of the distribution of isoporic lines

unsymmetrical character of so great a part of the total change in the Earth's field makes it evident that we have not to do with a simple phenomenon which can be referred to a single cause, but one which arises from a combination of causes, some solar, some terrestrial, and some perhaps cosmical. These different sources of the observed changes may be and quite probably are wholly unrelated. Therefore progress toward a solution of the entire problem requires that these causes be distinguished and separated so far as possible. To this end especial and continuous attention should be given to the changes taking place in those regions recognized as centers of unusual and rapidly varying secular-change activity, for it is known now that in most cases where the annual rate of change of an element is large, the accelerations of that rate are likely also to be large, and only unremitting attention will secure the entire picture before it is forever lost. Ad. Schmidt[6] writes that "in view of the great lack of uniformity of the secular variation over the Earth's surface, the only proper procedure is to investigate with a varying degree of thoroughness the different regions in accordance with the irregularity prevailing in them." These regional changes, provisionally assumed to arise from crustal changes beneath them, appear to be superimposed upon those presumably connected with the slow and comparatively steady shift of the magnetic axis or change in the Earth's magnetic moment which may be considered as the true secular variation. Not only then will that problem be measurably simplified by an intensive study of the active regions, but there is also the prospect that interesting light will be thrown on some of the fundamental questions of the Earth's interior as well.

[6]Carnegie Inst. Year Book, No. 30, 298-299 (1931).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

DISTRIBUTION OF MAGNETIC ELEMENTS AND OF THEIR ANNUAL CHANGES IN THE VICINITY OF THE MAGNETIC POLES

By Boris P. Weinberg

A certain picture referring to the distribution of magnetic elements and, particularly, to their annual changes in the vicinity of the magnetic poles can greatly reduce the difficulties in tracing the corresponding isolines, the poles being peculiar points and therefore capable to provide useful indications.[1]

Owing to the meagerness of the number of observations not only around the south, but also around the north magnetic pole, it is interesting to make an attempt to form an idea on the distribution of magnetic isolines and especially of magnetic isopors on the basis of theoretical considerations.

Let us assume as a first approximation that the distribution of magnetic elements around a magnetic pole P (Fig. 1) for an epoch t_0 corresponds to such a uniform magnetization of the Earth as would give at this point a total intensity F directed vertically and equal to its actual value Z_0. Under this assumption the value of magnetic potential U at point K is

$$U = Mx/r^3 \tag{1}$$

where M is the magnetic moment of the Earth, r is the distance of the point K to the center O of the Earth, and x and y are the coordinates of K measured from the center O in the direction of the magnetic axis OX and in the direction OY perpendicular to it.

The values of the vertical and the horizontal components at the point K after some transformations are obtained from (1) in the form

$$Z = +(\partial U/\partial x)x/r + (\partial U/\partial y)y/r = -2xM/r^4 \tag{2}$$

$$H = -(\partial U/\partial x)y/r + (\partial U/\partial y)x/r = -yM/r^4 \tag{3}$$

Z being taken as positive upwards, and H as positive towards the magnetic pole.

Denoting the radius of the Earth by R and introducing the value

$$Z_0 = -2M/R^3 \tag{4}$$

and the magnetic latitude ψ we have

$$Z = xZ_0/R = Z_0 \sin\psi \tag{5}$$

$$H = yZ_0/2R = (Z_0/2)\cos\psi \tag{6}$$

$$\tan I = 2x/y = 2\tan\psi \tag{7}$$

These results follow also from the theory of an infinitely small magnet at the center of the Earth.

[1] B. P. Weinberg, Preliminary summary of data on the present distribution of magnetic declination within the Arctic Zone, Terr. Mag., **36**, 273-278 (1931) abstract; J. Geophys., Leningrad, No. 4, 254-260 (1932).

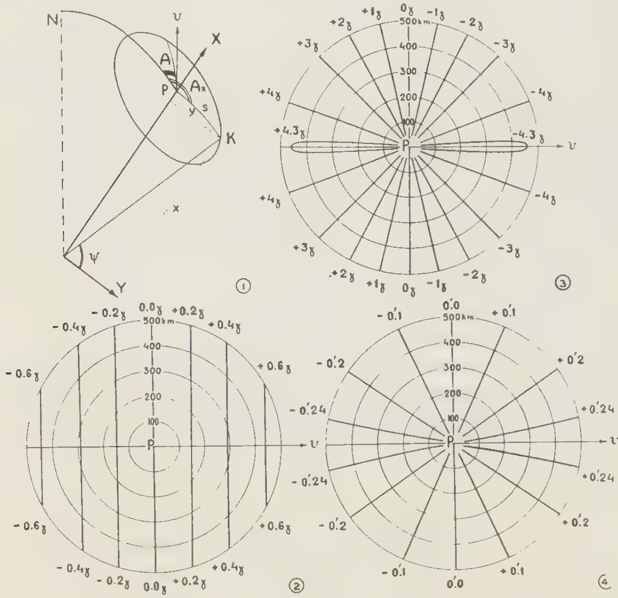
If we call s the distance of the point K from the magnetic pole along the Earth's surface the gradients of Z, H, and I in moving from pole P will be

$$dZ/ds = -(1/R)(dZ/d\psi) = -Z_0 \cos\psi \tag{8}$$

$$dH/ds = -(1/R)(dH/d\psi) = (Z_0/2)\sin\psi \tag{9}$$

$$dI/ds = -(1/R)\, d \arctan 2 \tan\psi/d\psi = -2/R\,(4 - 3\cos^2\psi) \tag{10}$$

If for the north magnetic pole we admit according to Fisk[2] $Z_0 = 0.61$ C.G.S., we have for the points I, II, III, IV, and V, distant 100, 200, 300, 400, and 500 km from the pole, the values given in Table 1.



FIGS. 1, 2, 3, AND 4

The subscripts NE and SW denote the values of the corresponding elements in points distant 100, 200, 300, 400, and 500 km from the pole in the directions northeast and southwest, these values being taken from Fisk's charts and the mean values ofthe two are indicated.

The comparison of the theoretical values with the chart-values of Fisk shows that notwithstanding the striking non-coincidence of the distribution of Z (it is sufficient to point out that the maximum of Z lies about 2000 km to the south from the pole) and the resulting asymmetry of the distribution of H and I, the general picture of the distribution of H and I and of their gradients, deduced from theoretical considerations, is more or less congruent with the observations.

[2]H. W. Fisk, Isomagnetic charts of the arctic area, Pub. Nat. Res. Council, Trans. Amer. Geophys Union, 12th annual meeting, 134-139 (June 1931).

TABLE 1—*Theoretical (Weinberg) and charted values (Fisk) of magnetic elements Z, H, and I, and their space-variations in the arctic regions for approximate epoch 1925*

Value	Points at distance in km from magnetic pole				
	I—100	II—200	III—300	IV—400	V—500
$90°-\psi$	0° 54′	1° 48′	2° 42	3° 36′	4° 30′
	γ	γ	γ	γ	γ
Z, theoretical	60,993	60,971	60,934	60,882	60,815
Z_{NE}, charted	60,700	60,500	60,200	59,900	59,600
Z_{SW}, charted	61,300	61,600	62,000	62,300	62,700
$(Z_{NE}+Z_{SW})/2$	61,000	61,050	61,100	61,100	61,150
H, theoretical	479	957	1476	1914	2393
H_{NE}, charted	400	900	1500	2200	3000
H_{SW}, charted	400	800	1200	1500	1800
$(H_{NE}+H_{SW})/2$	400	850	1350	1850	2400
I, theoretical	89°33′	89°06′	88°39′	88°11′	87°44′
I_{NE}, charted	89.°0	89.°1	88.°7	88.°2	88.°0
I_{SW}, charted	89.0	88.4	87.9	87.4	87.1
$(I_{NE}+I_{SW})/2$	89.0	88.8	88.3	87.8	87.6
	γ/km	γ/km	γ/km	γ/km	γ/km
dZ/ds, theoretical	−0.151	−0.301	−0.452	−0.601	−0.752
dZ/ds_{NE}, chart	−0.28	−0.26	−0.26	−0.28	−0.30
dZ/ds_{SW}, chart	+0.31	+0.33	+0.35	+0.37	+0.40
dH/ds, theoretical	−4.790	−4.788	−4.785	−4.781	−4.776
dH/ds_{NE}, chart	−4.5	−5.5	−6.5	−7.5	−8.5
dH/ds_{SW}, chart	−4.0	−3.8	−3.5	−3.0	−2.5
	′/km	′/km	′/km	′/km	′/km
dI/ds, theoretical	−0.270	−0.269	−0.268	−0.267	−0.265
dI/ds_{NE}, chart	−0.27	−0.25	−0.23	−0.21	−0.18
dI/ds_{SW}, chart	−0.48	−0.32	−0.30	−0.24	−0.18

The latter circumstance gives the possibility of using the data of Table 1 in order to determine the theoretical form of the isopors around the magnetic poles, if we assume as a point of issue that the displacements of the pole have as consequence the parallel displacement of the whole of the isomagnetic lines surrounding the pole in the same direction without any distortion of these lines. Therefrom if we take as known the velocity v km per year of the motion of the pole and its direction given by the azimuth A (from north to south through east), we can determine

the annual changes $Z' = dZ/dt$, $H' = dH/dt$, and $I' = dI/dt$ at different points in the vicinity of the pole, similar to those determined by me for the declination.[1]

Indeed, if we denote by A_K the azimuth of the radius-vector connecting the point K with the pole P, we have (see Fig. 1)

$$Z' = dZ/dt = (dZ/ds)\,(ds/dt) = -Z_0\, v \cos\psi \cos(A - A_K) \quad (11)$$

$$H' = dH/dt = (dH/ds)\,(ds/dt) = [Z_0\, v \sin\psi \cos(A - A_K)]/2 \quad (12)$$

$$I' = dI/dt = (dI/ds)\,(ds/dt) = 2v \cos(A - A_K)/R\,(4 - 3\cos^2\psi) \quad (13)$$

The values of Z', H', and I' resulting from (11), (12), and (13) for the points lying northeastward from the north magnetic pole under the assumption[1] $v = 0.9$ km per year with $A = 45°$ east of north are given in Table 2 and the resulting isopors are represented by Figures 2, 3, and 4.

Figures 3 and 4 may be of help in constructing isoporic charts of I and H for the polar regions—especially if the above mentioned asymmetry of the distribution of H and I be taken into consideration and might introduce some corresponding changes in the very interesting isoporic charts given by Fisk.[3]

Table 2—*Secular-change rates (Z', H', and I') in magnetic vertical intensity, horizontal, intensity, and inclination for points 100, 200, 300, 400, and 500 kilometers northeast of the north magnetic pole for approximate epoch 1925*

Secular-change rate	Point and distance in km NE of pole				
	I—100	II—200	III—300	IV—400	V—500
Z', γ per year	+0.136	+0.271	+0.407	+0.541	+0.677
H', γ per year	−4.311	−4.310	−4.307	−4.303	−4.298
I', ′ per year	+0.243	+0.242	+0.241	+0.240	+0.238

[3]H. W. Fisk, Isopors and isoporic movements, Comptes-Rendus de l'Assemblée de Stockholm, Union Geod. Geoph. Intern., Sect. Terr. Mag. Electr., Bull. No. 8, 280-292 (1931).

Central Physical Observatory,
Leningrad, U.S.S.R.

DISTRIBUTION OF MAGNETIC OBSERVATORIES AND SECULAR-VARIATION STATIONS

By J. A. Fleming

In terrestrial magnetism and electricity, as in most physical sciences, coordination of data and experiment must pave the way for the development and test of theory—a coordination which Bauer so consistently emphasized and which was so materially forwarded through his efforts during the many fruitful years he directed the scientific research of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The problems presented are extremely complex and so interrelated with other physical, geophysical, and cosmical ones that they offer great resistance to attack; their solutions, therefore, call in marked and exceptional degree for international cooperative endeavor. Herein appears to lie the most promising hope of ultimate successful interpretation, in whole or in part, of the many complexities and variations shown by these fields of the Earth and of its atmosphere.

In the collection of data through the magnetic survey of the Earth, paramount attention must be given to the geographical and space-distributions and to the time-variability characterizing the phenomena concerned. Such work must include not only isolated observations on land and sea to determine the geographic distribution and long-period variations but also continuous work at fixed observatories to follow the time-variations simultaneously with coordinated observations in the physical laboratory and in astrophysical observatories.

In geophysics we must regard our Earth as one great laboratory in which Nature is constantly carrying on experiments. Unfortunately means are not yet available by which the magnetic and electric phenomena of the Earth may be observed from a distance as is the case in the astrophysical laboratory of space. In many ways this places the geophysicist at a much greater disadvantage than the astrophysicist because he must establish many observatories to get data for statistical studies. He has the additional disadvantage that systematic records of terrestrial magnetism date only a century back—far too short a time to arrive at conclusions regarding the real nature and causes of the phenomena and of their world-wide and cosmical relations.

The contribution through continuous work at fixed observatories was initiated by Gauss in the establishment in 1832 of a magnetic observatory at Göttingen to measure variations of declination and horizontal intensity. Following this, with the assistance of Weber and Humboldt, Gauss aroused such interest that international cooperation for the extension of the survey to magnetically unexplored regions was effected soon after 1840 in the establishment of a number of observatories in widely separated parts of the world and in the development of instruments for determining with precision all three magnetic elements and their variations.

Naturally, pending the opening of new territory in the western and southern hemispheres, the most intensive distribution of existing permanent observatories is in Europe (see Fig. 1). Schmidt[1] as long ago as 1898, using a careful mathematical analysis and taking account of the extent to which the uncertainty affecting the results obtained for the

[1] Beitr. Geophysik, **3**, 225-246 (1898); see also Zs. Geophyssik, **4**, 299-304 (1928).

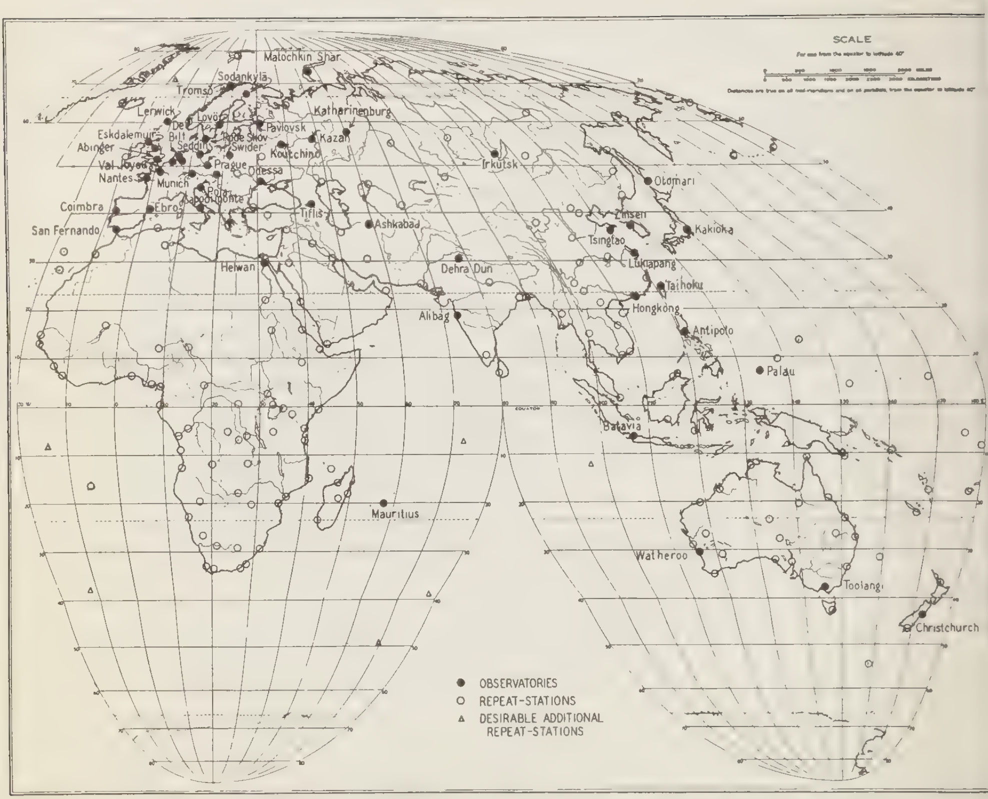


FIG. 1—Locations of existing magnetic observatories, repeat-stations, and desirable additional repeat-stations in the Eastern Hemisphere

then existing net of observatories, indicated how that world-net should be increased by the addition of a minimum number of suitably chosen observatories to insure data of optimum value in the discussion of world-wide magnetic phenomena. He showed how every involved law is hidden or in doubt less because of the limited number of observatories than because of their distribution. How serious this lack of distribution is may be readily seen upon inspection of Figures 1 and 2 upon which the existing observatories are indicated by the full black circles.[2] The distribution is even more unsatisfactory than indicated thus graphically because many of the observatories fail to completely reduce and publish all results—unfortunately occasioned by the constant urge by various governments to reduce expenses involved in efforts other than those showing immediate practical utilization. Indeed, for some of the observatories there are great accumulations of recorded data absolutely

[2]For compilations of latest values of the magnetic elements at existing observatories see J. A. Fleming. Latest annual values of the magnetic elements at observatories, Internat. Geod. Geophys. Union, Sect. Terr. Mag. Electr., Bull. No. 8, 244-264 (1931); also Terr. Mag., 35, 165-177 (1930).

FIG. 2—Locations of existing magnetic observatories, repeat-stations, and desirable additional repeat-stations in the Western Hemisphere

untouched as regards analysis, reduction, and publication. It is paramount in any consideration of the question of magnetic research to stress the need of effecting for scientific utilization full and prompt publication of results without which research on the intricate magnetic problems and their correlated phenomena of such growing importance in application to everyday use is hampered.

Valuable information already existing regarding the magnetic and electric conditions of the Earth and of its surrounding atmosphere and envelope in the upper strata, restricted as it is to limited portions of the Earth's surface, must be supplemented by better distribution of continuous registrations as well as of secular-variation observations at field-stations. Further progress is bound to be retarded until the observatory-net is increased by establishing additional observatories at strategic points in the southern hemisphere and at places in the northern hemisphere, but particularly in equatorial and polar regions. The limiting conditions of the phenomena prevailing in the arctic and antarctic have long been recognized as the potential source of that particular information

so necessary in the study of magnetic disturbances, their propagations, and their causes. Further attention must be given to securing fixed stations at points of approximate equal magnetic latitude and as regards the asymmetric portion of the Earth's magnetic field. To cite an example of recent advances in theory demanding additional data for test and improvement, reference may be made to Chapman's researches and speculations on the theory of magnetic storms.[3] The great importance of additional equatorial stations is indicated by the results more recently shown by the discussion of data from the Huancayo Magnetic Observatory in Peru—practically on the magnetic equator; already these show anomalous results at least as regards various theories proposed. The lack of such observatories and of a better network in the southern hemisphere seriously impedes mathematical analyses leading to the real solution of such problems in terrestrial magnetism as those of diurnal variation and propagation of magnetic disturbances, of cosmical bearings of magnetic disturbances, and of relation between magnetic activity and solar activity.

While we have a general knowledge of the nature of magnetic disturbances, advance in fundamentals calls for more extensive foundations upon which to build and which may be obtained only through systematic additions to the present network of observatories and a systematized selection of stations on land and sea for secular-variation determinations. More open time-scales with accurate time-control are necessary for the recognition and study of the characteristic features including those of diurnal variation, of the time of simultaneous disturbances, and of the damped waves following perturbations. There also is need of better theoretical foundations for really representative scales to characterize magnetic and electric activities upon which to build relations with physical and cosmical phenomena regarding the character of those electric currents causing irregular and regular perturbations. To these ends additional observatories should be established and distribution-stations should be decided upon in regions where auroral displays are frequent and where limiting conditions of the other phenomena prevail. In the regions above latitude 60° north and below 50° south—eighteen per cent of the Earth's surface—there are very few data, the natural result of the relative inaccessibility and lack of development and habitation. Therefore, advantage must be taken of every opportunity to encourage work in these regions by polar expeditions and particularly to encourage and stimulate simultaneous efforts such as those of the International Polar Year Commission.

The increasing application of knowledge of the Earth's magnetic and electric fields to geophysical prospecting and to even more valuable scientific research on the geology and details of the Earth's crust and interior is such that countries heretofore active or inactive in these fields should for economic reasons consider intensive work at field-stations and at observatories. Recent rapid development of special instruments and standardized equipment now make it more feasible than ever to obtain international coordination most efficiently. Cooperative research in physical laboratories and astronomical observatories are evolving and offer much promise. Upper-air research, essential not only to study of problems of terrestrial magnetism and electricity but also to practical

[3]See Terr. Mag., **36**, 77-97 and 171-186 (1931), and **37**, 147-156 (1932).

considerations of the effects of the magnetic and electric fields upon radio, telegraphic, and telephonic communication, evidences the direction which the development of methods at magnetic and electric observatories must take in the future.

Unfortunately the very complexities of the phenomena enhanced by the heterogeneous structure of the Earth's crust give rise to magnetic anomalies superimposed on what might otherwise be a simple uniform magnetization. So much of the Earth's surface is water, for which as yet we lack instrumental means to establish in its vast extent recording observatories, that a suitable distribution is indeed difficult. The theoretical requirements must give way before the necessities of practical economics, particularly when it is remembered that every magnetic observatory requires, in addition to its original cost, a considerable sum in the yearly maintenance of personnel and operation, to say nothing of the requirements of publication.

The practical impossibility of realizing a network of continuously recording observatories close enough together to permit direct interpolation to correct survey-data for diurnal variation and to determine secular variation with that accuracy necessary to theoretical investigation calls for provision to determine diurnal variations for each of the elements at selected secular-variation field-stations. Comparisons of such data with records obtained simultaneously at the nearest surrounding observatories must increase our limited knowledge of the way in which the range, time of extremes, and other characteristics of the diurnal variations change from place to place and in the two hemispheres.

Reference to Figures 1 and 2 brings out clearly, among other things, the great lack of fixed observatories in Africa. Additional observatories are needed in the Belgian Congo, in French West Africa, in Somaliland, and in Cape Colony. It is to be hoped, therefore, that the observatories which have been established by the French Government in French West Africa, by the Italian Government in Eritrea, and by the Belgian Government in Belgian Congo in connection with the International Polar Year program of 1932-33 may be made permanent by those governments. In South America, while there are several observatories, it is quite apparent from Figure 2 that the addition of an observatory at Pará in the equatorial belt would be of inestimable advantage in geophysical science —an advantage and a responsibility which the Brazilian Government should not hesitate to accept. As regards the vast expanse of the oceans, the Argentine Government has been operating for some years a station on the South Orkneys (Orcadas); this valuable station should be continued and its records reduced and published. Other stations in the oceanic areas where observatories could be established with profit include Kerguelen Island, St. Helena, Tristan da Cunha, Easter Island, Solomon Islands or New Caledonia, and Guam. The relative inaccessibility of the antarctic continent and the difficulty of life there may prohibit the establishment of a permanent observatory in that part of the world, but the experience of the Byrd Antarctic Expedition indicates that it would by no means be infeasible to establish a permanent station there, for example, at Little America; a station on Macquarie Island would go far to improve the distribution if a station in lower latitudes is not possible. In the arctic, thanks to the efforts of the Scandinavian governments and those of the Union of Soviet Republics, there is now a fine distribution of

observatories in the eastern hemisphere. A very desirable additional arctic station in the western hemisphere is indicated at Chesterfield Inlet, and it is to be hoped that the Canadian Government, in establishing this station for the International Polar Year program of 1932-33, will make this a permanent addition to the world-net.

As previously indicated, only a minor fraction of the Earth's surface is occupied by nations possessing sufficiently broad scientific interest in this subject to take up the dual responsibility of establishing magnetic ob-observatories and of conducting systematic surveys at stated intervals. The interest of other nations needs the stimulation which comes from a better understanding of the close relation between magnetic and other terrestrial forces—signs of such growing interest are appearing in many places. The problem of magnetic secular-variation, perhaps more than any other of geophysical questions of great interest, demands international cooperation. The ever-changing lines of magnetic force of the Earth take no account of national boundaries. Now, and probably for a long time in the future, the assistance of those best able to afford it will be required to maintain the collection of data from the great areas of both land and sea which a satisfactory discussion of secular variation demands.

That there may be no unwise expenditure of effort or of money in duplication of surveys or in observing in regions where the need from the point of view of secular-variation needs—is less to the neglect of other regions where the requirements are much greater, a definite plan of international cooperation should be agreed upon and maintained. The formulation of such a plan requires consideration of the general character of the secular-variation phenomena and the distribution of the areas where the rates of change are of such special interest as to demand the continuous records only obtainable at fixed observatories, as well as preliminary decision as to what data are considered necessary, what number of stations may be sufficient, and what period of time may be allowed between observations at field-stations to give most satisfactory results.

Provisional isoporic charts[4] (charts showing lines of equal annual change) have been prepared in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for magnetic declination, inclination, horizontal intensity, vertical intensity, and total intensity. These charts indicate a few significant facts which must be taken into account in considering the number and distribution of magnetic observatories and of permanent repeat-stations. Among these are: (1) Isopors tend to form closed ovals around certain foci of very rapid annual-change; (2) the accelerations or changes of rate from year to year are generally very large near these foci; (3) the arrangements of rapid change are not permanent but appear to undergo changes in form or position in so brief a time as one or two decades; (4) these foci are practically all in one hemisphere, that bounded by the meridians 90° east and 90° west and containing most of the land of both hemispheres.

It is with consideration of these points that the repeat-stations indicated in Figures 1 and 2 have been tentatively suggested for international discussion in adopting a plan for repeat-observations. The preliminary steps to realize such a plan were taken in August 1930 at the Stockholm Assembly of the International Union of Geodesy and Geo-

[4]See H. W. Fisk, Isopors and isoporic movements, Internat. Geod. Geophys. Union, Sect. Terr. Mag. Electr., Bull. No. 8, 280-292 (1931).

physics. The Association of Terrestrial Magnetism and Electricity there, recognizing the great importance of simultaneous researches of the secular variation over the entire globe, appointed two subcommittees charged with considering (1) the selection of sites of new observatories for terrestrial magnetism and electricity and the examination of a net of observatories well distributed over the globe and the distribution of observatory work in Europe, and (2) the question of secular variation over the whole globe. At the Innsbruck meeting of the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization in September 1931, that Commission expressed its wish to collaborate with these sub-committees of the International Association and to obtain the support of the International Meteorological Organization in establishing a net of observatories for the purpose of increasing as much as possible our knowledge without increasing the expense. That Commission was also in entire agreement as to the great importance of the formulation of a secular-variation program and further emphasized the value of a long series of observations, expressing the wish that governments or authorities consider favorably the continuation of work of observatories from which long series are already available.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

REVIEWS AND ABSTRACTS

(See also page 260)

Fleming, J. A. (Editor): *Transactions of the American Geophysical Union; Thirteenth annual meeting, April 28 and 29, 1932.* Washington, D. C., National Research Council, June, 1932 (401 with illus.). 25 cm.

The Transactions before us contain the reports and papers presented at the general assembly and at the meetings of the seven sections which constitute the American Geophysical Union, held in Washington, D. C., on April 28 and 29, 1932.

At the general assembly, ten resolutions proposed by the general assembly and the various sections were read and adopted. These referred to the following matters: (1) Urgent need of continuing oceanographic work without material curtailment, (2) gravity-work at sea by the United States Navy, (3) purchase of apparatus for determining gravity at sea, (4) Naval Observatory time-signals, (5) need of non-governmental reasearch institutions in meteorology, (6) commendation of "Geophysical Abstracts" published as an information circular by the United States Bureau of Mines, (7) Second International Polar Year 1932-33, with reference to the work carried out by the United States Coast Guard, and expressing the hope that it may be found possible to carry out further oceanographic determinations in the region of the Grand Bank and Davis Strait, and incidentally make other geophysical observations during the Polar Year, (8) death of Alfred Judson Henry, (9) death of Robert DeCourcy Ward, and (10) death of Louis Agricola Bauer.

As this issue of the Journal is dedicated to the memory of the last-named member of the Union, it is fitting that the Tenth Resolution be quoted in full:

> "Whereas, The American Geophysical Union has learned with profound regret of the death of Louis Agricola Bauer, founder and late director emeritus of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and mindful of the active interest

which he has taken in the affairs of the Union and of the important services he has rendered in the advancement of geophysics, particularly in the initiation and conduct of a magnetic survey of the Earth and in the analysis of the results thus obtained, therefore be it

"Resolved, That the American Geophysical Union, in general meeting assembled, records this expression of its sense of loss in the death of Louis Agricola Bauer, and be it further

"Resolved, That copies of this resolution be sent to Dr. Bauer's family, to the President of the Carnegie Institution of Washington, and to the Acting Director of the Department of Terrestrial Magnetism."

The general assembly was devoted to a symposium on the application of geophysics to oceanic basins and margins at which nine papers were presented dealing with various aspects of the subject.

The sectional meetings were characterized by numerous reports on geophysical activities, not only in the United States, but also in Canada and Mexico. In the Section of Geodesy, papers were presented dealing with gravity-work, isostacy, instrumental developments, lunar influence on latitude, and aerial photogrammetry. The meeting of the Section of Seismology was devoted to a "Symposium on the application of seismology to the study of ocean-basins." In the Section of Meteorology, programs arranged for the International Polar Year 1932-33 and for the solar eclipse of August 31, 1932, were presented and papers given bearing on winds in the upper atmosphere and in the Antarctic, atmospheric turbidity and water-vapor, interrelations between air- and ocean-temperatures in California and the northeast Pacific, weather-charts of the northern hemisphere, and fifty years of rainfall in North America. The communications to the Section of Oceanography, in addition to progress-reports pertaining to the development of oceanographical research in the United States, included discussions of light-penetration into the sea, of formation of submarine valleys, of oceanic surveys of temperatures and the temperature-gradients in oceanic waters, of Arctic and Atlantic interchanges, of radium-content of ocean-bottom sediments, etc. Papers presented to the Section of Volcanology dealt with Central American volcanoes in 1932, volcanic developments in 1931-32, and volatility of silica with steam. In the Section of Hydrology, the meetings were devoted to the presentation of the reports of its nine permanent committees and 21 papers by authors from federal, state, university, and consulting-engineering organizations.

The papers and reports presented at the Section of Terrestrial Magnetism and Electricity, fall more properly within the field represented by this Journal and included the following: Summary of magnetic and electric work of organizations in the United States during 1931-32, by H. W. Fisk. The reports, thus summarized, fifteen in number, are also given in full, and deal with the progress made along a large number of lines including: Magnetic observations, magnetic standards, magnetic surveys, magnetic discussions, magnetic instruments, earth-currents, atmospheric electricity, space-charge, lightning, thunder-storms, ionization, aurorae, height of the Kennelly-Heaviside layer, correlations, and earth-resistivity and geophysical prospecting. The following papers were presented: On the calculations of the ionization in the upper atmosphere, by E. O. Hulburt; The geophysical significance of radio measurements of the ionized layer, by M. A. Tuve; Kennelly-Heaviside-layer measurements on the Byrd Antarctic Expedition, 1929-30, by M. P. Hanson; Some common periodicities in radio transmission-phenomena, by G. W. Kenrick and G. W. Pickard; Radio exploration of ionization of the upper atmosphere, by J. H. Dellinger; Progress in the studies of cosmic correlations with radio reception at the Perkins Observatory, by H. T. Stetson; Slow-moving ions in the atmosphere, by G. R. Wait and O. W. Torreson; Principles of a new portable electrometer, by R. Gunn; Optically-compensated variometers and wide-range recorders to be used during the Jubilee Polar Year, by H. F. Johnston; and the relation of lightning-discharge to changes in the electrical field of thunder-storms, by J. C. Jensen.

The reports presented indicate that good progress has been made in the United States along all lines of geophysical research. The Transactions of this thirteenth annual meeting, which are far more voluminous than those for previous years, have been produced by the economical and rapid photo-offset process and constitute a volume of up-to-date information, worthy of the Union and its contributing members, and of its General Secretary to whom is due the excellent form in which it has been published.

H. D. Harradon

MAGNETIC CHARACTERIZATION OF DAYS

By G. van Dijk

At its meeting in Paris in September 1900, the International Meteorological Committee, on the recommendation of the Magnetic Commission, adopted a resolution that the directors of the magnetic observatories be requested to furnish periodically a list of the days which they considered as calm. Dr. Maurits Snellen, member of the Commission and director of the De Bilt Observatory was, from the end of 1903, entrusted with collecting and distributing these lists.

At the meeting of the Commission in Innsbruck in September 1905, it was resolved that the magnetic observatories should be requested to prepare, beginning January 1, 1906, statements showing the magnetic character of each day on the scale 0 to 2, proposed by Professor Ad. Schmidt: 0, to indicate calm days; 1, disturbed days; and 2, very disturbed days. It was left to the discretion of the individual directors to fix limits for defining these divisions. The collection and distribution of the statements were again confided to Dr. Snellen.

This is the history of the origin of the quarterly tables of the "Caractère magnétique de chaque jour"; after the death of Dr. Snellen in 1907, the Royal Netherlands Meteorological Institute at De Bilt assumed the task of editing and publishing the tables.

The first issue, January to March 1906, appeared in August 1906 and contained data from 15 contributing observatories; this number gradually increased so that at the end of 1906, 35 stations were collaborating. In 1931 the number was 49, and embraced nearly all the magnetic stations of the globe which were able to forward their lists to De Bilt in time for inclusion in the tables, namely, before the end of the succeeding quarter.

In the annual reviews of the "Caractère magnétique de chaque jour" the methods of classification of the contributing observatories have been given as far as possible; they have been partly modifications of the System of Eschenhagen (for example, 0 for class 1 of Eschenhagen, 1 for classes 2 and 3, 2 for classes 4 and 5), partly based on the amount of the deviation from the regular diurnal oscillation, and partly on other principles, in which frequency, duration, and nature of the perturbation play a part.

The annual reviews give for each day the sum of the character-numbers assigned by all stations which have sent in lists for the whole year, the mean value, and a graphical representation of all daily mean values. These mean values, the so-called international character-numbers, have proved of great use for the study of the variations of terrestrial magnetism and allied phenomena, periodicities, solar activity, aurorae, disturbances in radio transmission, etc.

In "Ergebnisse der magnetischen Beobachtungen im Jahr 1911" for Wilhelmshaven, Bidlingmaier gave a method of expressing in absolute measure the variability of a phenomenon, which he developed more in detail for the variations of the Earth's magnetism. By introducing the

quantity "activity" he purposed to give a measure of the energy-change connected with these variations. He proposed choosing the year 1915 for a study of the Earth's magnetic activity, some observatories having already promised cooperation.

De Bilt decided to participate also; the labor required for the different calculations was rather extensive and had to be accomplished in spare time not occupied by regular work. Hence the work was not completed until the beginning of 1922. In the first part of the paper "Activity of the Earth's magnetism and magnetic characterization of days" (K. Ned. Met. Inst. Meded. en Verh. **27**) the computations were made chiefly according to the method of Bidlingmaier; in the second part various criteria, suggested as measures of the Earth's magnetic activity, and their relationships, were discussed.

The Rome meeting of the International Union of Geodesy and Geophysics took place in 1922. I did not have the opportunity of attending the meeting, but was able to send my paper to Dr. Bauer, Secretary of the Section of Terrestrial Magnetism and Electricity, before his departure from Washington for Europe. I feel much indebted to him for having given a summary of my paper in a "Note on a simple measure of the Earth's daily magnetic activity," presented at the Rome meeting.

This note gave a table and a graphical representation of monthly mean measures of daily magnetic activity based on the De Bilt magnetic observations for 1915 for the following quantities: Activity A_d^z proposed by Bidlingmaier; $\Sigma(R_D^2 + R_H^2 + R_Z^2)/100 = \Sigma R^2/100$, proposed by Chree ($R$ = absolute daily range of an element in γ); $\Sigma\ (A_D + A_H + A_Z) = \Sigma\ A$, proposed by Schmidt ($A$ = daily range of hourly mean values); $\Sigma\ (R_D + R_H + R_Z) = \Sigma\ R$, proposed by van Dijk; ϵHR_H, a reduction of an expression of the energy-change: $dW = (2/3)\ \rho^3\ (XdX + YdY + ZdZ/4)$, where ρ = radius of the Earth, proposed by Bauer; and $\Sigma\ C$ = sum of magnetic character-numbers of 35 stations, together with some other quantities related to solar activity.

As a result of the discussions in Rome it may be stated that the quantity suggested by Bidlingmaier was found to be too complicated and some less complicated method was desirable. It was finally agreed to appoint a committee to give further consideration to the matter.

Since 1922 the question of magnetic characterization has formed a subject for discussion at the meetings of international magnetic organizations. Other measures of magnetic activity have been suggested; for example, Bartels' interdiurnal variability u, in 1923, and Ono's variability, drafted after the meeting of the Magnetic Commission of the International Meteorological Committee in Utrecht in 1923. The computation of these measures is somewhat laborious.

Before the meeting of the Section of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics in Prague in 1927, Dr. A. Crichton Mitchell had collected observations for a great number of magnetic stations and discussed different criteria, mainly for the month of January 1920, as follows: ΣR; $\Sigma R^2/100$; $HR_H/10000$; $(HR_H + ZR_Z)/10000$; $\Sigma\ XF_x/1000$, that is, one-thousandth of the product of the mean value of a component for the day into the mean hourly range of that component for the day and these products for the three components X, Y, Z being summed together; $\Sigma\ A$; $\Sigma\ (R_x - R_{xm})^2$, that is, the sum for three components, of the squares of

the difference between the absolute daily range and the least absolute daily range during the month.

In Prague a subcommittee was appointed with Dr. Chree as chairman to propose a definite choice of the criteria suggested for magnetic characterization of days. After Dr. Chree's death, Dr. A. Crichton Mitchell acted as reporter and recommended for adoption as the measure of magnetic activity the value $(HR_H + ZR_Z)/10000$, which, following trials of all the suggested criteria, was found to satisfy most of the conditions that may be laid down for such criteria.

The Section of Terrestrial Magnetism and Electricity at its meeting in Stockholm, August 19, 1930, concurred in this opinion and, after the De Bilt Observatory had signified its willingness to undertake the collection of the data and the distributing of the reports, adopted the following resolutions:

(1) That the International Union of Geodesy and Geophysics recommends to the International Meteorological Conference that the Magnetic Commission of the latter body should arrange for the extension of the present magnetic character-scheme by inviting all observatories included in that scheme to forward to De Bilt, along with the usual magnetic character-data, a statement showing the value for each Greenwich day of $(HR_H + VR_V)/10000$, or in the case of observatories which record N, W, and V, of $(NR_N + WR_W + VR_V)/10000$ (N, W, H, and V are, respectively, the north, west, horizontal, and vertical components, and R_N, R_W, R_H, and R_V the absolute daily ranges of these components).

(2) That a list of these values, as from January 1, 1930, should be published along with the usual magnetic data for each quarter.

(3) That the Section of Terrestrial Magnetism make an annual grant not exceeding £100 to De Bilt Observatory to meet any additional outlay involved in clerical work or printing which may be required.

These recommendations were discussed at the meeting of the Magnetic Commission of the International Meteorological Organization, of September 21, 1931, in Innsbruck. The desirability was expressed at this meeting of publishing not only the quantities mentioned but also the quantities $HR_H/10000$, $ZR_Z/10000$, etc., separately, because of the interest of knowing these quantities themselves and their mutual relations, which differ for different days and for stations situated in different parts of the globe.

The new desiderata were inserted in a resolution, which was adopted by the Commission and approved by the International Meteorological Committee at its meeting of October 5, 1931, in Locarno. Early in November 1931 all magnetic observatories contributing to the "Caractère magnétique de chaque jour" were invited in a circular letter to forward to De Bilt statements showing for each Greenwich day the values of the quantities mentioned above. In the circular letter hints were given for computing the data requested by an easy method of sufficient accuracy.

It is possible to compute for special investigations the ranges R_H and R_Z from HR_H and ZR_Z if the values of H and Z are given. In the new publication the values of R_H and R_Z are not given because of lack of the necessary funds, arising partly from the extension of the tables to include the values of $HR_H/10000$, $ZR_Z/10000$, etc., and partly from the depreciation of the English pound with respect to the Dutch florin, which now makes £100 equal only to about 900 florins or less instead of

1200 florins. Hence the utmost care is required to prevent exceeding the annual grant.

Volume I of the new periodical "Caractère magnétique numérique des jours" was published in January 1932; it contains data for nine magnetic stations for January to December 1930. Volume II appeared in April 1932 and gives data for 22 stations for 1930 and 1931. The next volume will contain data for the first quarter of 1932 and those for 1930 and 1931 which were not received in time for publication in the former volumes. When this article was written (July 20, 1932), 21 stations had forwarded data for the first quarter of 1932 and three stations had sent their lists for the second quarter, showing that prompt forwarding of the reports may be expected after the observatories have systematized the preparation of their reports.

Altogether 30 magnetic stations have sent statements for the years 1930, 1931, and 1932. Arranged in order of latitude from north to south these are: Sodankylä, Lerwick, Lovö (Stockholm), Sitka, Copenhagen (Rude Skov), Eskdalemuir, Meanook, Seddin, Swider, De Bilt, Abinger, Val Joyeux, Vienna (Auhof), Agincourt, Tortosa (Ebro), Cheltenham, San Fernando, Tucson, Lukiapang, Helwan, Honolulu, Bombay, San Juan, Antipolo, Kuyper (Batavia), Huancayo, La Quiaca, Watheroo, Pilar, and Toolangi—24 stations in the northern and six in the southern hemisphere. When considering that in 1931, 49 stations contributed to the "Caractère magnétique de chaque jour" (scale 0, 1, 2) —40 in the northern and 9 in the southern hemisphere— it is found that proportionally the contribution to the new publication from the southern hemisphere is somewhat superior to that of the northern. Although the contributing stations belong to all five continents, there are large areas of the globe not yet represented.

The majority of stations give values of HR_H and ZR_Z; one station, probably lacking vertical-intensity records, gives only HR_H, and another gave in the beginning only HR_H but later upon the installation of a vertical-intensity variometer has supplied both HR_H and ZR_Z. Eskdalemuir, Seddin, and De Bilt give values of XR_X, YR_Y, and ZR_Z. Since Eskdalemuir, with a view to the observations during the International Polar Year, has changed its set of X-, Y-, and Z-variometers into a set of H-, D-, and Z-variometers, that station will probably in future supply values depending on H and Z. De Bilt is recording both H, D, and Z and X, Y, and Z, and gives values with H and Z as well as with X, Y, and Z.

In my paper on activity I remarked that at De Bilt YR_Y is rather small with respect to XR_X owing to the small value of Y and D. This is also the case for most of the other magnetic observatories, since at most the declination is rather small. Out of 49 observatories having contributed in 1931 to the "Caractère magnétique de chaque jour," declination-values are between 0° and 1° (east or west) at six stations, between 1° and 3° at six, between 3° and 5° at six, between 5° and 10° at twelve, between 10° and 15° at fourteen, and above 15° at five.

For the year 1919 I found for De Bilt as the mean of 362 days on which the records of both X and Y were complete, $XR_X/10000 = 163.2$, $YR_Y/10000 = 40.5$, thus making ratio $XR_X/YR_Y = 4.03$. Corresponding values at Eskdalemuir for 1919, 1920, 1930, and 1931, at Seddin for

1930 and 1931, at De Bilt for 1919, 1920, 1930, and 1931, are given in the following table with the values of X, Y, and D.

Observatory	Year	$XR_X/10000$	$YR_Y/10000$	XR_X/YR_Y	X (North)	Y (West)	D (West)
					γ	γ	° ′
Eskdalemuir. . .	1919	164.9	48.7	3.39	15985	4880	16 58.7
	1920	139.3	40.5	3.44	15990	4836	16 49.7
	1930	188.0	42.4	4.44	16036	4232	14 47.1
	1931	122.3	32.2	3.80	16000	4170	
Seddin.	1930	112.0	11.5	9.71	18300	1900	5 38.6
	1931	80.0	9.7	8.26			
De Bilt.	1919	163.2	40.5	4.03	18036	3693	11 34.3
	1920	143.6	34.3	4.19	18034	3637	11 24.2
	1930	184.2	32.5	5.66	18000	3000	9 26.3
	1931	124.6	25.3	4.92	18000	2940	9 15.7

There is an interval of 11 years between 1919, 1920 and 1930, 1931. In view of the relation between sunspot-frequency and range of regular and irregular variations of terrestrial magnetism, it may be expected that the mean regular daily ranges and the mean ranges of disturbances will not differ considerably. The yearly means of relative sunspot-numbers R were as follows: 1919, 63.1; 1920, 38.7; 1930, 35.7; and 1931, 20.7. The values of X were almost equal in the two pairs of years, so the difference in the values of YR_Y and in the ratio XR_X/YR_Y in the two pairs of years may to a large extent be ascribed to the value of Y having decreased at Eskdalemuir from 4800γ to 4200γ and at De Bilt from 3600γ to 3000γ. YR_Y is smallest with respect to XR_X at Seddin, where Y and D are smallest. It is largest at Eskdalemuir where Y and D are largest. Noteworthy is the large decrease of XR_X and YR_Y from 1930 to 1931 in accordance with the decrease of R from 35.7 to 20.7. Likewise the mean international character-number of 1931 was smaller than that of 1930, namely, 0.66 and 0.83 respectively. Although from 1930 to 1931 Y was decreasing, XR_X/YR_Y also decreased at all three stations, which proves that the matter is rather complicated and that the ranges of different elements play a more important part than the elements themselves.

For 348 days of 1919 the following values result for the De Bilt data: Of $XR_X/10000$, 154.3; of $HR_H/10000$, 150.6. The corresponding values in 1930 were, 184.2 and 177.7, and in 1931, 124.6 and 122.0. For all years XR_X is larger than HR_H, although H is larger than X. It is evident that $HR_H \neq XR_X + YR_Y$ when R_H, R_X, and R_Y are absolute daily ranges of H, X, and Y. Indeed, $H\triangle H = X\triangle X + Y\triangle Y$, when the times between which the variations of H, X, and Y are measured, are simultaneous for all elements. On inquiring into the matter I found that in the first half of 1930 at De Bilt on about three-fifths of the days the times of the highest and lowest values of H and X were the same or nearly so, and different on two-fifths of the days. For other observatories the ratio may be different—more coincidences when D is smaller, less when D is larger. When D is small, the H- and X-curves generally show

much conformity. When $\triangle Y$ represents the variation of Y between the times of maximum and minimum of H and X, $HR_H = XR_X + Y\triangle Y$, where $\triangle Y$ may be positive or negative, that is, in the same or in opposite direction to the variations of H and X. One of the reasons why HR_H may turn out to be smaller than XR_X is that on many days the minimum of H and X (at about 11^h) occurs towards the time of maximum of Y (about 13^h).

At De Bilt the yearly means of XR_X and ZR_Z have about the same value: Thus means of 362 days in 1919 are 163.2 and 176.4; for 1920, 143.6 and 142.8; for 1930, 184.2 and 174.7; for 1931, 124.6 and 130.2 respectively. The values of X and Z in 1930 and 1931 were practically the same as in 1919 and 1920.

At stations at higher latitudes ZR_Z is larger than XR_X or HR_H. At stations near the magnetic equator XR_X or HR_H is predominant. At Huancayo—where the inclination is smaller than 2°, $H = 29600\gamma$, and $Z = 900\gamma$—the yearly mean of HR_H in 1930 was 554.5 and of ZR_Z was 2.5.

The remarks about the mutual relations of H and X and of HR_H and XR_X when D is small may, *mutatis mutandis*, be made about F and H (F = total intensity) and FR_F and HR_H when I is small, that is, near the magnetic equator as at Huancayo, and for F and Z and FR_F and ZR_Z when I is large, that is, near the magnetic poles. Data for magnetic observatories where inclination approaches 90° are not available; it is to be expected that stations established near the magnetic poles during the International Polar Year will afford interesting material.

Koninklijk Nederlandsch Meteorologisch Instituut,
De Bilt, Utrecht, Holland

THE MAGNETIC CHARACTER OF THE YEAR 1931 AND NUMERICAL MAGNETIC CHARACTERIZATION OF DAYS

By G. Van Dijk

The annual review of the "Caractère magnétique de chaque jour" for 1931 has been drawn up in the same manner as for the preceding years.[1] Forty-nine observatories contributed to the quarterly tables; forty-four of them sent complete data.

Table II of the annual review, containing the mean character of each day and each month, the lists of calm days and disturbed days, and the days recommended for reproduction are reprinted here.

In the introduction a note has been inserted concerning numerical magnetic characterization of days. According to the resolutions of the Section of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics of August 19, 1930, in Stockholm, and of the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization of September 21, 1931, in Innsbruck, tables have been prepared, showing for each Greenwich day the values of $IIR_H/10000$, etc., of magnetic stations. These tables have been published along with the tables of "Caractère magnétique de chaque jour." Two volumes of the new publication "Caractère magnétique numérique des jours" have now appeared, containing data of January to December 1930, and of January to December 1931, respectively.

Dates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1931															
January	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.1	0.5	0.3	0.2	0.0	0.6
February	0.7	0.9	0.7	0.7	0.4	0.0	0.4	0.2	0.2	0.1	0.2	0.0	1.8	1.5	1.3
March	0.2	0.8	0.9	0.3	0.4	0.2	0.6	0.8	0.7	0.9	0.2	1.2	1.4	1.0	0.4
April	0.9	0.3	0.9	0.6	0.2	0.1	0.1	0.3	0.7	1.0	0.8	0.0	0.0	0.1	0.2
May	0.1	0.4	0.2	0.2	0.4	1.1	1.7	0.4	0.0	0.0	1.0	0.8	1.2	1.3	1.4
June	1.3	1.7	0.9	0.3	0.2	0.6	0.3	1.0	1.3	0.8	1.0	1.0	0.5	0.5	0.2
July	0.2	0.9	0.5	0.6	0.2	0.2	0.4	0.3	0.1	0.0	0.7	0.6	0.6	0.8	0.8
August	0.4	0.2	0.7	0.4	0.6	0.4	1.0	1.4	1.2	0.8	0.8	0.3	0.5	0.4	0.3
September	0.8	0.1	1.1	1.5	0.8	1.3	1.1	1.1	0.9	0.7	0.5	0.6	0.4	0.9	1.5
October	1.2	1.6	0.9	1.2	1.5	0.8	0.5	0.4	0.3	0.4	0.3	1.5	1.3	0.7	0.9
November	0.6	0.6	0.8	1.2	1.4	1.4	1.0	1.6	1.1	0.9	0.6	0.0	0.8	1.1	1.3
December	1.0	1.5	1.4	1.4	1.3	0.9	0.4	0.3	0.4	1.0	1.3	1.1	0.8	0.8	0.9

Dates	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Means
January	1.4	1.4	1.3	0.8	0.9	0.3	0.2	0.2	0.1	1.2	1.0	0.8	0.9	0.8	0.1	0.5	0.54
February	0.7	0.6	0.2	0.2	0.1	0.0	0.3	0.4	1.8	1.4	1.2	1.0	0.3				0.62
March	0.2	0.2	0.0	0.1	0.8	1.3	0.8	0.6	0.3	0.7	1.1	0.6	0.5	0.5	0.1	0.4	0.59
April	0.1	0.3	0.9	1.3	1.3	0.3	0.4	0.3	0.2	0.5	0.6	0.1	0.2	0.0	0.2		0.45
May	0.8	0.5	0.6	0.2	0.5	0.3	0.1	0.1	0.1	0.7	1.0	0.5	0.0	0.7	0.2	0.1	0.54
June	0.1	0.0	0.2	0.3	0.2	0.8	0.7	0.4	0.3	0.1	1.5	1.4	1.4	0.7	0.2		0.65
July	0.7	0.3	0.2	0.1	0.0	0.1	0.1	1.7	1.0	1.3	0.9	0.5	1.3	0.8	0.6	0.2	0.55
August	1.0	0.2	0.2	0.9	1.5	1.2	0.3	0.4	0.9	1.4	0.9	0.9	0.9	0.3	0.2	0.4	0.68
September	1.5	1.3	0.4	0.2	1.0	1.1	0.9	0.9	0.9	0.5	0.6	0.7	0.0	0.2	1.1		0.82
October	0.4	1.1	1.2	1.1	0.8	0.9	1.0	0.9	0.6	0.3	0.8	1.1	1.3	2.0	1.8	1.1	0.95
November	1.4	1.0	1.3	1.1	0.8	0.3	0.0	0.4	0.4	0.4	1.5	1.1	0.3	0.4	0.2		0.83
December	0.8	0.8	0.1	0.0	0.0	0.0	0.3	0.9	0.1	1.0	0.1	0.0	1.1	1.2	1.2	1.0	0.74

[1]Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930); **36**, 255 (1931).

Month	Calm Days						Most Disturbed Days				
January	(0.04)	**3**,	**7**,	**8**,	**24**,	**30**	**10** (1.1),	**16** (1.4),	**17** (1.4),	**18** (1.3),	**25** (1.2)
February	(0.06)	**6**,	**10**,	**12**,	**20**,	**21**	**13** (1.8),	**14** (1.5),	**15** (1.3),	**24** (1.8),	**25** (1.4)
March	(0.12)	**6**,	**11**,	**18**,	**19**,	**30**	**12** (1.2),	**13** (1.4),	**14** (1.0),	**21** (1.3),	**26** (1.1)
April	(0.07)	**6**,	**12**,	**13**,	**14**,	**29**	**1** (0.9),	**3** (0.9),	**10** (1.0),	**19** (1.3),	**20** (1.3)
May	(0.05)	**9**,	**10**,	**22**,	**23**,	**28**	**6** (1.1),	**7** (1.7),	**13** (1.2),	**14** (1.3),	**15** (1.4)
June	(0.11)	**5**,	**15**,	**16**,	**17**,	**25**	**2** (1.7),	**9** (1.3),	**26** (1.5),	**27** (1.4),	**28** (1.4)
July	(0.07)	**9**,	**10**,	**19**,	**20**,	**21**	**23** (1.7),	**24** (1.0),	**25** (1.3),	**26** (0.9),	**28** (1.3)
August	(0.20)	**2**,	**12**,	**17**,	**18**,	**30**	**8** (1.4),	**9** (1.2),	**20** (1.5),	**21** (1.2),	**25** (1.4)
September	(0.21)	**2**,	**18**,	**19**,	**28**,	**29**	**4** (1.5),	**6** (1.3),	**15** (1.5),	**16** (1.5),	**17** (1.3)
October	(0.34)	**9**,	**10**,	**11**,	**16**,	**25**	**2** (1.6),	**5** (1.5),	**12** (1.5),	**29** (2.0),	**30** (1.8)
November	(0.18)	**12**,	**21**,	**22**,	**28**,	**30**	**5** (1.4),	**6** (1.4),	**8** (1.6),	**16** (1.4),	**26** (1.5)
December	(0.04)	**19**,	**20**,	**21**,	**26**,	**27**	**2** (1.5),	**3** (1.4),	**4** (1.4),	**5** (1.3),	**11** (1.3)

Days Recommended for Reproduction

**October 29, 1931; *February 13, February 24, June 2, June 26, July 23, October 5, 1931.

Koninklijk Nederlandsch Meteorologisch Instituut,
De Bilt, Utrecht, Holland

REVIEWS AND ABSTRACTS

(See also page 251)

Defant, A. (Herausgeber): *Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschungs- und Vermessungsschiff "Meteor" 1925-1927.* Herausgegeben im Auftrage der Notgemeinschaft der Deutschen Wissenschaft. Band I. *Das Forschungsschiff und seine Reise*, von F. Spiess. Band X. *Die biologischen Methoden und das biologische Beobachtungsmaterial der "Meteor"-Expedition*, von E. Hentschel. Berlin und Leipzig, Verlag von Walter de Gruyter u. Co., 1932. 29 cm.

Under the editorship of Dr. Albert Defant two volumes, I and X, of the scientific reports of the German Atlantic Expedition on the *Meteor* have recently appeared. Volume I of 442 pages is largely devoted to the narrative of the expedition written by Admiral Fritz Spiess who was in command of the vessel and was leader of the Expedition following the untimely death of Dr. Alfred Merz. In addition to the narrative this volume contains a description of the vessel, its construction, mechanical and sailing equipment, trials, and preliminary cruise, by Spiess and Engineer Officer J. Nixdorff. Another chapter describes the navigation and determination of position.

Perhaps of chief interest to the readers of this periodical is the discussion, by Dr. Kurt Hessen, of the magnetic work carried out at the five land stations. Serious instrumental difficulties were encountered, but the observers made the best of the situation and obtained approximate values which are compared with chart-values and earlier measurements made by the German South-Polar Expedition during the first Polar Year, by the *Carnegie* on Cruises II and IV, and by a Carnegie Institution field-observer in 1915. Secular variation is discussed, measurements are reduced to epoch, and values and chart-differences are given in tabular form.

A chapter on the mechanical operation by Nixdorff, another on the medical history of the Expedition by the Medical Officer, Dr. Karl Kraft, and an abstract of the log complete the volume which is well illustrated with photographs and charts.

Volume X is the first of a series dealing with biology and is prepared by Dr. Ernst Henschel. It contains 274 pages, of which 50 are devoted to a description of the apparatus, methods, and work, the rest of the volume being taken up with data regarding the collections and a catalog of specimens.

F. M. Soule

MAGNETIC ACTIVITY—NUMERICAL MAGNETIC CHARACTER OF DAYS

By C. R. Duvall

Abstract—A table of monthly, equinoctial, solstitial, and annual means of the new measure is given for 1930 and 1931 at 17 observatories. Curves of the monthly means are given which show (1) good agreement in the time of maxima and minima at the different observatories; (2) the difference in value and range in value at the different observatories, the far northern observatories having large values, those near the equator small; (3) the decrease in amplitude for 1931 as compared with 1930; this decrease is very nearly in the same proportion as the corresponding decrease in sunspot-numbers. The question of reducing the amplitudes of the new measure to a common basis is discussed. A table of statistics of the 17 observatories and of the new measure is given to aid in this discussion. No satisfactory result is arrived at, and it appears questionable whether such a result is possible. The monthly means of the new measure are analyzed for both years at the 17 observatories and the results given in a table. A discussion of this table and a comparison with some results given by Chree leads to the conclusion that a seasonal variation in the new measure is well established.

Having worked under Bauer's immediate direction during his last fifteen active years, when a large part of his work was on magnetic activity and closely related parts of the field of terrestrial magnetism, it is an especial privilege to make a contribution on this subject to this memorial number of the JOURNAL founded by him. He always took the greatest interest in magnetic activity, and among his writings will be found many valuable papers on this subject. It was largely due to his activity in the Section of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics that at the Stockholm Assembly in 1927 the new measure "numerical magnetic character of days" was adopted.

A brief discussion[1] was made of the results at the two magnetic observatories of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for the years 1929 and 1930, of the new measure of magnetic activity (Caractère magnétique numérique des jours). It was found in that discussion that the most characteristic feature of the new measure was the seasonal change. This was seen, first, in the monthly means themselves; second, in the residuals from an adjustment of these monthly means to a linear relation between them and Dr. Bartels' u-measure; and, third, in a comparison by seasons of the simultaneous daily values of this measure and of the international character-numbers.

Now that the Royal Meteorological Institute of Holland has published Tomes I and II "Caractère magnétique numérique" much more material is available. For the primary purpose of further investigating the seasonal change, the following discussion considers the results at those observatories only for which values are available for both 1930 and 1931. Results for 13 such observatories are published in Tomes I and II, and in additon we have those for 1931 at San Juan and Sitka kindly furnished by the Director of the United States Coast and Geodetic Survey, and the 1931 results at the Department's two observatories at Watheroo and Huancayo. This makes a total of 17 observatories for which complete data are at hand for the two years.

Table 1 gives the monthly means, seasonal means, and annual means for the 17 observatories. It will be observed, of course, that this con-

[1] C. R. Duvall, Terr. Mag., **36**, 311-314 (1931).

TABLE 1—*Numerical magnetic character of days* $(HR_H + ZR_Z)/10000$

Year	Month	Sodankylä	Sitka	Rude Skov	De Bilt	Abinger	Val-Joyeux	Agincourt	Tortosa	Cheltenham	Tucson	Lukiapang	Honolulu	Bombay	San Juan	Huancayo	La Quiaca	Watheroo
1930	Jan.	1402	1080	315	231	235	188	200	214	252	268	241	204	310	197	676	307	524
	Feb.	2151	1320	522	317	313	227	321	272	360	256	247	225	305	230	648	302	523
	Mar.	2136	1665	543	360	371	288	432	318	362	240	291	218	344	202	649	304	527
	Apr.	3150	2285	747	476	488	359	662	416	535	331	371	234	377	232	685	304	565
	May	2645	2032	697	467	480	355	1022	352	592	310	321	241	306	220	558	275	497
	June	2316	2130	611	419	435	316	1085	359	585	304	322	223	326	188	480	215	466
	July	1888	1596	526	361	389	279	628	271	402	265	260	209	286	173	462	198	426
	Aug.	2489	1773	585	392	404	297	739	333	453	287	260	201	296	215	480	202	456
	Sep.	2291	2135	568	366	392	308	788	299	466	304	341	233	365	198	569	250	527
	Oct.	2398	1823	598	367	374	304	619	340	419	256	301	205	358	214	553	259	539
	Nov.	1339	1036	342	258	260	212	285	213	257	200	215	187	267	187	489	261	471
	Dec.	1221	900	347	213	228	181	236	195	218	180	253	159	265	181	447	233	431
Jan., Feb., Nov., Dec.		1528	1084	381	255	259	202	260	224	272	226	239	194	287	199	565	276	488
Mar., Apr., Sep., Oct.		2494	1977	614	392	406	315	626	344	445	283	326	222	361	212	614	279	540
May, June, July, Aug.		2334	1882	605	410	427	312	869	329	508	292	291	218	304	199	495	222	462
Year 1930		2119	1648	533	352	364	276	585	299	408	267	285	212	317	203	558	259	496
1931	Jan.	916	486	204	153	170	136	179	151	181	186	216	160	237	165	538	229	375
	Feb.	1206	710	283	213	210	167	260	180	236	186	224	182	247	189	450	220	447
	Mar.	1104	547	248	194	219	172	172	185	213	196	199	183	272	185	510	229	348
	Apr.	821	494	269	222	253	204	174	193	243	219	280	211	283	171	484	220	302
	May	874	682	308	246	278	218	297	204	297	229	247	192	259	184	376	157	273
	June	1104	779	344	264	289	234	264	242	312	236	228	190	256	185	335	180	246
	July	954	731	309	248	270	218	224	227	276	230	220	184	274	162	401	157	271
	Aug.	1345	984	336	266	280	219	280	214	300	260	234	197	269	183	405	178	326
	Sep.	1947	1166	431	309	309	218	273	230	286	233	279	191	302	188	491	235	398
	Oct	2354	1400	610	380	372	272	440	319	369	246	272	194	314	197	541	257	476
	Nov.	1983	1084	429	287	274	196	215	270	242	202	225	165	281	153	410	205	441
	Dec.	1493	795	330	242	230	167	165	196	195	189	208	145	242	150	424	231	404
Jan., Feb., Nov., Dec.		1400	769	312	224	221	167	205	200	213	191	218	163	252	164	456	221	416
Mar., Apr., Sep., Oct.		1556	902	389	276	288	216	264	232	278	224	258	194	293	185	506	235	381
May, June, July, Aug.		1070	794	324	256	280	222	266	222	296	238	232	190	265	178	380	168	279
Year 1931		1342	822	342	252	263	202	245	218	262	218	236	183	270	176	447	208	359

densed table does not give the tenths, that is, for nearly all the observatories one less figure is given than is published. It is not felt that any actual accuracy is sacrificed by this rounding off. This is certainly true in the case of the observatories of greater latitude, where the values and the ranges of the values are large.

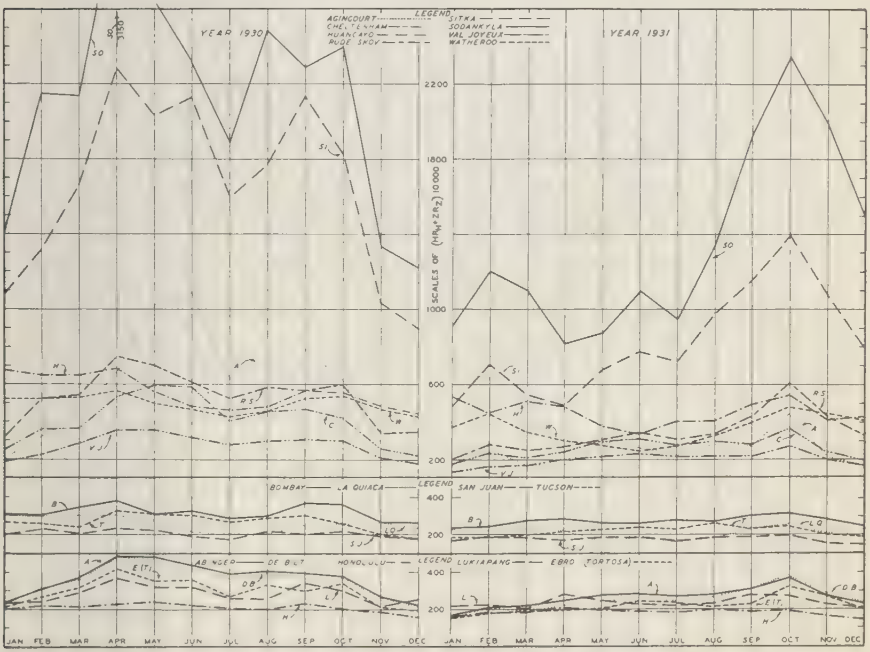


FIG. 1

The monthly means are plotted in Figure 1. For the stations of greater latitude the seasonal variation is immediately apparent on account of its greater amplitude. The flatness of the curves for stations near the equator is another principal feature. Also, in general, greater amplitudes go with greater values, as seen in Table 2. From the figures it also may be concluded that there is something in this measure common to the observatories, which is not common to the two years. This is seen, first, in the fact that for 1930 the maximum value is reached in April for nearly all the observatories, Agincourt and, to a less degree, Cheltenham, being the only outstanding exceptions; second, in the fact that for 1931 the maximum is reached in October for 14 of the 17 observatories; third, in the fact that the annual mean is greater for 1930 than for 1931 for all observatories. The ratio of the annual mean for 1930 to that for 1931 varies from 2.4 at Agincourt to 1.2 for seven of the observatories at the lower latitudes. The mean of the annual mean of all the observatories for 1930 is 540, while that for 1931 is 356. The ratio of the 1930 value to that for 1931 is 1.52. The ratio of the annual mean relative sunspot-number for 1930 to that for 1931 is 1.68. The

ratio of the value for 1929 to that for 1930 is 1.82. The corresponding ratio of the annual means of the new measure of magnetic activity is 1.0 for Huancayo and 0.9 for Watheroo. All the observatories show a better agreement with the sunspot-ratio for 1930 and 1931, and the mean of all observatories is strikingly close. The failure of Huancayo and Watheroo to show a decrease of magnetic activity with a decrease of sunspot-numbers between 1929 and 1930 is not surprising, perhaps, when it is recalled that Bartels found almost no correlation between the monthly mean of his u_1-measure and of the sunspot-numbers for 1928-30[2].

In the discussion of values at Watheroo and Huancayo for 1929 and 1930, it turned out that summer values were higher than those of winter. Except for San Juan, where they are equal, this is seen to be true at all observatories for 1930, by means of Table 1, remembering that for the southern hemisphere summer is in January, February, November, December. There is just one exception to this rule for 1931. Sodankylä is the only observatory of the 17 where the summer value is not greater.

The similarity in the time or phase of the results at the different observatories will be considered more in detail below. Consider now the great range in value or amplitude at the different observatories. If our new measure of activity is to play the rôle expected of such a measure, it will be necessary to find some basis on which these amplitudes may be reduced to approximately the same value for the different observatories. The last three columns of Table 2 aim to show how far this is possible under certain suppositions.

The column f_{30} gives for each observatory the factor by which the annual mean must be multiplied to give the mean of the annual means of all the observatories for 1930. For example, $2119\times0.255=540$ for Sodankylä and $496\times1.089=540$ for Watheroo. For 1931, f_{31} is computed in the same way. If all the annual means of a year are multiplied by the same factor, the reducing factors of the derived series for that year, computed as described above, remain unchanged. Therefore, we may substitute for the 1931 values those gotten by multiplying each value by 1.519, and the derived series, with the same mean as that for 1930, will still have the same reducing factors as given under f_{31}. Also the 1931 annual means presumably may be reduced to the same sunspot-number as those of 1930 by multiplying each by 1.684. The new series for 1931, derived in this way, will have the same reducing factors f_{31}.

In the reduction of his interdiurnal variability of the north component to the same basis for different observatories, Bartels found that if he regarded the variability at each observatory as the component along the north line at that observatory of an action along the Earth's magnetic axis, the different observatories would give the same value along the magnetic axis. As the magnetic axis is supposed to change very slowly, this gives an approximately constant reduction-factor for each observatory. In this case, the question of direction of action is not embarrassing as any change in X must be along the north line, while for the new measure it is doubtful whether any direction of action can be assigned. If we put $\triangle H$ and $\triangle Z$ for R_H and R_Z, respectively, and ignore the question of ranges occurring at the same time, we may write, where F and $\triangle F$ are expressed in gammas

$$\triangle F=1/F(H\triangle H+Z\triangle Z)=10000/F \text{ (new measure)}$$

[2] J. Bartels, Terr. Mag., **37**, 1-52, especially 41 and 51 (1932).

TABLE 2—*Numerical magnetic character of days, statistics of stations, and annual values*

Observatory	Latitude north	Mag'c latitude	$\frac{10000}{F}$	New activity-measure: Annual mean 1930	Annual mean 1931	Ratio 1930/31	Range monthly means 1930	Range monthly means 1931	f_{30}	f_{31}	f_{30}/f_{31}
	°	°									
Sodankylä	67.4	63.6	0.197	2119	1342	1.58	1929	1533	0.255	0.265	0.96
Sitka	57.0	60.8	0.174	1648	822	2.00	1385	914	0.328	0.433	0.76
Rude Skov	55.8	52.9	0.209	533	342	1.56	432	406	1.013	1.040	0.97
De Bilt	52.1	49.7	0.214	352	252	1.40	263	227	1.534	1.411	1.09
Abinger	51.2	49.2	0.214	364	263	1.38	260	202	1.484	1.352	1.10
Val-Joyeux	48.8	46.6	0.218	276	202	1.37	178	136	1.957	1.760	1.11
Agincourt	43.8	61.5	0.169	585	245	2.39	885	275	0.923	1.451	0.64
Tortosa	40.8	38.0	0.230	299	218	1.37	221	168	1.806	1.631	1.11
Cheltenham	38.7	55.6	0.174	408	262	1.56	374	188	1.324	1.357	0.98
Tucson	32.2	40.5	0.192	267	218	1.22	151	74	2.023	1.631	1.24
Lukiapang	31.3	26.9	0.211	285	236	1.21	156	81	1.895	1.507	1.26
Honolulu	21.3	22.4	0.271	212	183	1.16	82	66	2.547	1.943	1.31
Bombay	18.9	13.4	0.242	317	270	1.17	112	77	1.704	1.317	1.29
San Juan	18.4	33.1	0.222	203	176	1.15	59	47	2.660	2.020	1.32
Huancayo	−12.0	0.8	0.338	558	447	1.25	238	206	0.968	0.795	1.22
La Quiaca	−22.1	− 6.2	0.371	259	208	1.25	109	100	2.085	1.710	1.22
Watheroo	−30.3	−46.1	0.176	496	359	1.38	139	230	1.089	0.990	1.10
Totals				9181	6045						
Means				540	356						
Ratio of means, 1930/1931				1.52							

That is, the new measure, multiplied by 10000 F gives $\triangle F$, the change in the total intensity, at the station in question. This multiplier is given in the fourth column of Table 2. The values are rough, as recent data were not available in all cases. If $\triangle F$ had a known direction at an observatory, it would be possible to find out whether the components at the different observatories all arose from the same action along the magnetic axis, but it is difficult to see how such a direction can be determined.

It may be seen in Table 2 that the multiplication of the annual means by the corresponding factors 10000 F has a tendency to bring the different observatories into better accord. That is, in general, the large values will be multiplied by small factors and the small values by large factors, but the resulting accord is far from satisfactory. The more serious difficulty in arriving at an accord in the amplitudes arises when we consider the two years. If there is to be a fixed reduction-factor for each observatory, as in the case of Dr. Bartels' interdiurnal variability, then each observatory must have the same factor for the two years. The last column of Table 2 shows how near this condition is satisfied. If the two factors were the same, the ratio in the last column would be unity, and the difference from unity shows the divergence from agreement. For Agincourt the divergence is 36 per cent below, and for San Juan 32 per cent above. These are the two extremes. It is to be remembered that the factors f_{30} and f_{31} are derived from a series of values which bear a constant ratio to the original observations, so the possibility of better ratios is not denied. Series gotten by multiplying the two years by 10000 F gave little if any improvement. The values in

the last column are also the ratios of the mean of all observatories for 1930 divided by the mean of all for 1931 to the annual mean of an observatory for 1930 divided by its annual mean for 1931; that is, for Sodankylä we have $f_{30}/f_{31}=1.52/1.58=0.96$, and so for the other observatories.

To give a numerical expression to the rise in values of the new measure at the equinoxes and to the fall at the solstices, which is brought out very clearly by Figure 1, the Fourier coefficients were computed of the first two terms of the monthly means. The results are given in Table 3. The agreement of the time of maximum is the test of accord in the annual variation at the different observatories.

As was to be expected, the agreement in the annual term is very much poorer than that in the semi-annual term. The mean of all first-term times of maximum for 1930 is about the middle of May and the range is about four and one-half months. With the exception of Bombay and San Juan, the northern stations all have their maximum times near the summer solstice, those of Bombay and San Juan falling near the vernal equinox. For this year the times of maximum of the three stations of the southern hemisphere occur in the latter part of February. The first term for 1931 has its mean maximum about the middle of August and a range of about seven months. This range is increased materially by the fact that Honolulu and San Juan reach maximum values about the middle of May, more than two months ahead of other northern stations. In this year the three stations farthest north—Sodankylä, Sitka, and Rude Skov—have maxima near the autumnal equinox. The maxima of the other nine northern stations all fall near the middle of August; those of the three southern near the December solstice. For both years the range of maximum values is increased considerably by combining stations of the northern and southern hemispheres. This increase is one month in 1930 and two and one-half months in 1931.

TABLE 3—*Amplitudes and phase-angles for monthly means of numerical magnetic character of days*

Observatory	Year 1930				Year 1931			
	c_1	c_2	θ_1	θ_2	c_1	c_2	θ_1	θ_2
			°	°			°	°
Sodankylä	548	476	296	269	590	295	160	244
Sitka	507	337	281	261	341	137	182	244
Rude Skov	146	101	293	259	110	77	182	227
De Bilt	100	55	291	252	62	40	198	228
Abinger	107	54	288	253	55	39	217	228
Val-Joyeux	67	47	284	250	39	24	235	225
Agincourt	363	106	271	210	58	36	210	251
Tortosa	69	52	295	258	43	32	197	211
Cheltenham	150	58	286	238	57	27	235	236
Tucson	46	18	291	290	32	8	240	261
Lukiapang	38	38	296	246	15	25	230	250
Honolulu	22	15	310	283	18	15	282	277
Bombay	11	16	0	279	18	25	207	258
San Juan	15	39	309	274	7	13	281	296
Huancayo[a]	83	67	28	298	50	56	93	297
La Quiaca	46	25	43	267	33	22	102	278
Watheroo[a]	25	47	34	273	94	35	118	282

[a]The amplitudes and phase-angles, c_1, c_2, θ_1, and θ_2, respectively, for 1929 were: For Huancayo 105, 59, 82°, and 298°; for Watheroo 96, 31, 109°, and 285°.

The second term for 1930 reaches its first mean maximum value about April 4 with a range of about one and one-half months. For 1931 the corresponding date is about April 9 with about the same range. For 1930 the stations giving the extreme values are Agincourt and Huancayo; for 1931 Tortosa and Huancayo. The analysis is also given for 1929 in the cases of Huancayo and Watheroo. Huancayo, which gave the earliest first maximum of the second term for both 1930 and 1931, has a range of less than one day in this maximum for the three years. For Watheroo the range for the three years is about six days. It will be observed that in the cases of these two observatories, for 1929 the maximum of the first term falls near the December solstice.

In "Studies in terrestrial magnetism", Table XXVII, page 84, Chree gives, among other things, the time of the maximum of the first term of the analysis of the Kew range in the diurnal variation in H as July 3, and in Z as June 19. For the first maximum of the second term the corresponding dates are April 6 and April 16. These dates are not very different from those gotten above in the analysis of the monthly means of the new activity-measure. If eleven-year means of the new measure were available, it would be interesting to know how the times would agree. Chree's dates are based on eleven-year means, omitting highly disturbed days.

From the above discussion it appears that we may regard it as established that there is a well marked seasonal change in the new measure (numerical magnetic character of days).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

NOTES

(See also pages 277, 290, and 316)

20. *International Polar Year stations 1932-1933*—The participation of the United States in the Polar-Year program through operation of a station at *College-Fairbanks*, Alaska, was assured when the appropriation of $30,000 authorized by the bill signed March 18, 1932, by President Hoover was included in the second deficiency bill passed by Congress July 1, 1932. This station, which will be under the direction of the United States Coast and Geodetic Survey, has been made possible by the united efforts of the State Department, the Department of Commerce through its Coast and Geodetic Survey and its Bureau of Standards, the War Department through its radio station at Fairbanks, the Navy Department through its Naval Research Laboratory, the Department of Agriculture through its Weather Bureau, the Carnegie Institution of Washington through its Department of Terrestrial Magnetism, the Alaska Agricultural College and School of Mines, the International Polar Year Commission, and certain private contributors. The group of American scientists taking part in the work at the station includes: Franklin P. Ulrich, Everett R. Johnson, and Harold F. Bennett of the Coast and Geodetic Survey; H. B. Maris and C. E. Johnson of the Naval Research Laboratory; a radio operator of the Signal Corps of the Army; W. J. Rooney and K. L. Sherman of the Department of Terrestrial Magnetism; and Prof. V. R. Fuller of the Alaska Agricultural College and School of Mines. Mr. Ulrich, who is in charge of the Sitka Magnetic Observatory of the Coast and Geodetic Survey, will resume his regular duties at

Sitka after the first three or four months of operation, when Mr. E. R. Johnson will be given charge of the station. Mr. Rooney will also remain at the station until October in connection with the installation of the earth-current and atmospheric-electric equipment assisting Mr. Sherman, who will have charge of that work after Mr. Rooney leaves. Dr. Maris will be in charge of the recording and experimental work in the radio investigations, while Prof. Fuller will continue his valuable parallactic auroral photographs and researches.

The Canadian Meteorological Service has arranged to occupy three stations in northern Canada. At *Chesterfield Inlet* the party will be in charge of F. T. Davies, formerly of the Byrd Antarctic Expedition and now on furlough, at the request of the Meteorological Service, from the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for this work. He will be assisted by B. W. Currie, Assistant Professor of Physics at Saskatchewan University, S. T. McVeigh, and John Rae. This station is about 475 miles from the north magnetic pole and is the nearest point to the pole at which continuous magnetic records will be taken during the Polar Year. The program, in addition to the meteorological, magnetic, and auroral work, will include continuous records of earth-currents using equipment provided by the Carnegie Institution of Washington. Records will also be made of the atmospheric-electric potential. A meteorological and auroral station is also being established at *Copper Mine* on Carnation Gulf on the Arctic Ocean in charge of R. C. Jacobsen. The third special station for meteorological and auroral observations is located at *Cape Hope's Advance* (61° north, 70° west) on Hudson Strait in charge of J. E. Lily, who will be assisted by the operators of the regular radio station there. This station will be an effective link between the Danish and French stations in Greenland and the North American stations in Canada and Alaska.

References have already been made in this Journal to the English station at *Fort Rae* which is already in operation under charge of J. M. Stagg and to the station at *Point Barrow*, Alaska, in charge of C. J. McGregor, as also to the four earth-current stations being especially established in the United States by the American Telephone and Telegraph Company centering at *Houlton*, Maine; *New York*, New York; *Wyanet*, Illinois, and *Tucson*, Arizona.

Meteorological, auroral, magnetic, radio, and other observations will be made by a party arranged under the direction of Joseph B. Dodge of the Appalachian Mountain Club on *Mount Washington* (6288 feet above sea-level), New Hampshire, during the coming winter. In this work Mr. Dodge has the cooperation of Dr. Charles F. Brooks, Director of the Blue Hill Observatory; Prof. J. W. Goldthwait of Dartmouth College, and Dr. N. E. Gilbert, also of Dartmouth, President of the New Hampshire Academy of Science. Three observers will live on the summit from October 15, 1932, to June 15, 1933.

We are pleased to learn that efforts are being made by the Archiv für Polarforschung in Kiel, under the leadership of Dr. Max Grotewahl, to establish a small private station in *Arsuk* (latitude 61°.2 north, longitude 40°.2 west), where high-speed magnetic registrations and auroral observations in connection with the station at Julianehaab are to be undertaken. If this attempt is crowned with success, as we hope will be the case, Germany will be represented by at least one polar station during the Polar Year.

In connection with the establishment of the French station at *Scoresby Sound* on the east coast of Greenland, where magnetic, electric, and other geophysical investigations are planned for the International Polar Year 1932-33, Prof. Ch. Maurain, director of the Institut de Physique du Globe, Université de Paris, accompanied the expedition on the "Pourquoi Pas?" which sailed the latter part of June. He plans to return to France on the vessels used for transporting the expedition.

THE FIELD ENERGY OF MAGNETIC STORMS

By S. Chapman

1—In this brief paper, written in honor of the memory of Louis A. Bauer, I return to the consideration of a topic which I discussed fourteen years ago,[1] when my ideas as to the nature of magnetic storms were much more clear cut than is now the case.

2—I then thought that magnetic storms were due primarily to electric currents flowing in high layers of the Earth's atmosphere. Such currents certainly seem to play an important part in the auroral regions, where the magnetic perturbations are greatest; but I no longer consider it likely that atmospheric-electric currents are responsible for the main magnetic changes over the middle belt of the Earth. It now seems to me probable that the principal change, the diminution in horizontal magnetic force during the main (second) phase of a magnetic storm, is due to an electric current-ring situated roughly concentric with the Earth, in the equatorial plane, the current flowing westward. This hypothesis has been proposed, on different grounds, by various writers, and, in particular, Störmer[2] has considered the effect of such a ring in modifying the position of the auroral zones, as inferred from his well-known auroral theory. More recently, Ferraro and I, in outlining a new theory of magnetic storms,[3] have suggested the formation of such a current-ring as a consequence of the projection towards the Earth of a neutral ionized stream of corpuscles from the sun.

There is an important difference in size between the ring-current on our theory, and that considered by Störmer; though we are as yet unable to work out the details of the formation of such a ring from a neutral stream of corpuscles, our tentative opinion was that the magnetic storm is produced by current flowing within a few Earth-radii from the Earth's centre. The Earth's radius is approximately 6400 km, and the mean radius R of the current-ring, in our view, would be from three to five times this, or 20,000 to 30,000 km. The latter, our upper limit, was the lower limit of R considered by Störmer (l. c. p. 73), whose upper limit was 10 million km; his more detailed calculations (l. c. pp. 95, 96) referred to values of R between 90,000 and 9 million km. It may be added that the ring-currents, on our respective hypotheses, differed not only in size; Störmer considered the ring to be composed of charges of one sign only, whereas Ferraro and I believe that it must be electrically neutral. A discussion of the ring-current will be included in a further instalment of our joint paper.

3—My object here is to estimate the change in the energy of the magnetic field round the Earth, during a storm, on the hypothesis that the storm is partly due to a ring-current of one or other kind.

4—Much of the discussion in my paper of 1918 is still relevant to the present case, and to avoid repetition I refer the reader to that paper

[1]The energy of magnetic storms, M. N. R. Astr. Soc., **79**, 70-83 (1918).

[2]C. Störmer, Arch. Sci. Phys., **32**, 277-314 (1911).

[3]Terr. Mag., **36**, 77-97, 171-186 (1931), and **37**, 147-156 (1932) to be continued.

for details and formulae. I there pointed out that the excess energy of the field during a storm could be divided into two parts, one, which I called the self-energy (S), being the energy of the disturbing field if the Earth's field were absent, the other, which I called the "joint-energy" (J), being due to the combined presence of the two fields. By expressing both fields in terms of spherical harmonic functions, I showed that in J the only term that needs consideration is due to the principal harmonic, P_1 (cos θ), in the Earth's magnetic potential, and the same term in the potential of the disturbing field; the argument remains valid in the present case, though the potential of the ring-current differs materially from that of the system of atmospheric currents considered in my former paper.

5—In fact, treating the current, for the moment, as a thin one, its potential, expressed in terms of polar coordinates r, θ relative to the Earth's centre and axis, is[4]

$$2\pi i \sum_{n=0}^{\infty} (-1)^{n+1} \frac{1\cdot 3\ldots(2n-1)}{2\cdot 4\ldots\ 2n} \left(\frac{r}{R}\right)^{2n+1} P_{2n+1}(\cos\theta)$$

for $r < R$, and

$$2\pi i \sum_{n=1}^{\infty} (-1)^{n+1} \frac{1\cdot 3\ldots(2n-1)}{2\cdot 4\ldots\ 2n} \left(\frac{R}{r}\right)^{2n} P_{2n-1}(\cos\theta)$$

for $r > R$. Thus the only term of importance for J is the first, namely

$$-2\pi i\ (r/R)\ P_1\ (\cos\theta) \text{ when } r<R, \text{ and}$$
$$\pi i\ (R/r)^2\ P_1\ (\cos\theta) \text{ when } r>R$$

The value of i, the current along the ring, will be expressed in terms of the magnetic field (δH_0) of the ring at the Earth's centre; then by a well-known formula

$$\delta H_0 = 2\pi i/R, \text{ or } i = R\ \delta H_0/2\pi$$

Thus the leading potential terms are, in terms of δH_0,

$$-r\delta H_0\ P_1\ (\cos\theta) \qquad \text{when } r<R, \text{ and}$$
$$(1/2)\ R^3\ \delta H_0\ P_1\ (\cos\theta)/r^2 \text{ when } r>R$$

The former agrees with the value which obtained on the hypothesis considered in my former paper (equation 12), while the latter is half the corresponding term there given (equation 11, where b takes the place of the present R).

6—The joint energy J is obtained by integration throughout three regions, the first being inside the Earth, the second between the Earth and the sphere of radius R, and the third the space beyond R. The first of these integrals is independent of any hypothesis as to the external cause of the storm, and my former value (equation 16).

$$(1/3)\ a^3\ H_0\ \delta H_0$$

where H_0 denotes the equatorial magnetic force (0.3 Γ) at the Earth's surface, is still valid; this, it is true, involves an assumption as to the

[4]Cf. Jeans, Electricity and magnetism, Ch. 13.

seat of the Earth's main field, but, as was pointed out, the above expression is in any case probably fairly near the truth.

The integral between the radii a and R vanishes, as before. The integral over the region beyond R is half that in the former case, because the corresponding term in the disturbing potential is now halved; this part of J is therefore now

$$(1/3)\ a^3\ H_0\ \delta H_0$$

(cf. equation 15 of the former paper). This is independent of R. The reason for this (at first sight) remarkable result is easily seen. For a given δH_0 the force due to the disturbing-potential term $(1/2)\ R^3\ \delta H_0 P_1/r^2$ will have a definite value, independent of R, over the sphere R, and a proportionately smaller value, in the ratio $(R/r)^3$, at greater distances. Thus, the greater R, the larger is the volume over which the disturbance field exceeds any chosen fraction of δH_0. The effect of this larger volume is, however, just compensated, so far as concerns the energy integral, by the smaller value of the Earth's field, proportional to $(a/r)^3$, over this volume, for the larger values of R.

Thus, in all, the value of J is approximately

$$(2/3)\ a^3\ H_0\ \delta H_0$$

being two-thirds of my former value.

7—The self-energy S will include a part arising from atmospheric-electric currents in auroral regions, as well as the part due to the ring-current; but it is easy to see that the former is relatively insignificant. The self-energy of the ring-current is best calculated from the coefficient of self induction (L) of the ring, which avoids the necessity of considering all the harmonic terms in the above expansions of the potential. Thus

$$S = (1/2)\ L\ i^2 = R^2\ (\delta H_0)^2\ L/8\pi^2$$

The value of L depends on the cross-section of the ring-current; I suppose, for illustration, that this is circular, and of radius c. Then approximately[5]

$$L = 4\pi R\ \left\{\log_e\ (8R/c) - 7/4\right\}$$

Hence

$$S = f\ R^3\ (\delta H_0)^2$$

where

$$f = (1/2\pi)[\log_e\ (8R/c) - 7/4]$$

8—The ratio of the self-energy to the joint-energy of the disturbing field is thus given by

$$S/J = (3\,f/2)\ (R/a)^3\ \delta H_0/H_0$$

The value of the last factor depends on the intensity of the storm considered; for illustration I suppose that $\delta H_0/H_0$ is 1/300, corresponding to $\delta H_0 = 100\gamma$ approximately. Then

$$S/J = (f/200)\ (R/a)^3$$

[5]Encyk. Math. Wiss., Leipzig, Bd. 5, Teil 2, p. 469, equation (197).

In this expression f is unknown, but rough limits for it can be assigned. In the new theory of storms proposed by Ferraro and myself, R seems to be of the order $3a$ to $5a$, and c is not likely to exceed a; thus R/c may be taken as not less than 3. So far as I know Störmer did not consider the radius c of the ring-current, but, in view of his larger values of R, we may suppose that R/c might on his hypothesis be as large as 1000. The values of f corresponding to $R/c = 3$ and $R/c = 1000$ are 0.3 and 1.1.

Thus, if R is only a moderate multiple of a (say $R \leq 5a$), as Ferraro and I are inclined to think, S/J is of the order $0.2 \times 1/200 \times 5^3 = 1/8$, that is, the self-energy is only a fraction of the joint-energy. This fraction is larger than I formerly calculated (which was about 1/600), as must obviously be the case on the new hypothesis here considered; but the important point is that the whole energy of the storm, $(J+S)$, is practically equal to J, which is of the same order as (actually two-thirds of) the value previously found.

If, however, R has the large values considered by Störmer, so that R/a is 100 or more (corresponding also to his hypothesis that the radio echoes of long delay are reflected by corpuscular sheets beyond the orbit of the moon), then S/J will be large, for example, if $f = 1$ and $R/a = 100$, $S/J = 5000$. On this view a magnetic storm involves far more field-energy than is the case in the alternative view here considered; this is natural in view of the large volume over which the field of Störmer's ring would extend.

In the case of the smaller ring ($R \leq 5a$), the field energy of a "standard" (100γ) magnetic storm is about 5×10^{22} ergs (practically independent of R). This value needs to be reduced by about a half on account of the part of the disturbing field induced within the Earth (l. c. §18). According to our new theory of magnetic storms, this energy comes from the kinetic energy of the neutral stream of corpuscles, but probably only a small fraction of the stream-energy is thus transformed.

Imperial College of Science and Technology
South Kensington, London, England

PERÍODO DIURNO, ANUAL Y SECULAR EN LAS PERTURBACIONES SÚBITAS DEL CAMPO MAGNÉTICO TERRESTRE

POR LUIS RODÉS, S.J.

Amablemente inivitado por el Director del Departamento Magnético de la Carnegie Institution a colaborar al número extraordinario de Terrestrial Magnetism and Atmospheric Electricity que dicha Institución quiere dedicar a la memoria del malogrado Director, Dr. Louis Agricola Bauer, y recordando su constante interés y extensos trabajos en el estudio de los comienzos súbitos de las tempestades magnéticas, me ha parecido tomar como tema de esta breve comunicación el estudio de la frecuencia periódica con que se producen los saltos bruscos de los imanes en el registro del campo magnético.

Como base del estudio, el P. Puig ha recorrido todas las curvas del archivo del Observatorio, unas 10,000 en conjunto, y de ellas ha entresacado 218 saltos bruscos, los cuales, clasificados por el mismo Padre siguiendo las indicaciones del autor de estas líneas, son analizados en este trabajo. Conviene notar que la selección se hizo con un criterio del todo ajeno al fin a que se destinaban, para evitar así toda influencia de ideas preconcebidas.

Atendiendo a la mayor o menor rapidez y amplitud del salto, se han distinguido tres tipos o categorías: *A*, *B*, *C*, de cuyas características dan idea las reproducciones de la Figura 1. En la primera categoría figuran 54 saltos, en la segunda 70, y en la tercera otros 70. Aunque, como es natural, no existe una línea divisoria bien marcada entre los tres tipos, la clasificación adoptada permite estudiarlos separadamente y señalarles mayor o menor peso según las circunstancias en que ha tenido lugar el salto brusco.

El efecto de la variación secular en la frecuencia de los saltos bruscos de los imanes queda patente en las curvas *A*, *B*, y *C* de la Figura 2. La primera ha sido obtenida dando el mismo peso a todos los casos registrados y es el resultado directo de la observación; para la segunda curva *B* se han tenido en cuenta las cualidades: (*a*) Naturaleza del salto, (*b*) carácter de la curva inmediatamente antes, y (*c*) carácter de la curva inmediatamente después; al salto mismo se le ha asignado el peso 1, 2, 3, según el tipo a que pertenece; en cuanto a la curva precendente se le ha dado el valor 1 ó 2, según que fuese de calma relativa o calma absoluta; y a la curva subsiguiente se le han asignado 1, 2, 3, según que fuese de débil pertubación, fuerte perturbación o violenta tempestad; el peso máximo con que puede figurar un comienzo súbito es 8 y el mínimo 3. La curva *C* se ha obtenido con sólo los saltos bruscos, considerados de primera categoría y ponderados según el criterio expuesto.

El paralelismo de las curvas *A*, *B*, y *C* demuestra que el resultado obtenido dando a cada salto su peso es el mismo que arroja la observación directa de los hechos sin clasificar. Las tres curvas ponen de manifiesto la estrecha relación que existe entre la actividad solar y la frecuencia de saltos bruscos en los imanes. Como primera consecuencia podemos, pues, afirmar que los cambios repentinos de intensidad en las componentes del campo magnético terrestre vienen regulados por la actividad solar y obedecen a causas extraplanetarias.

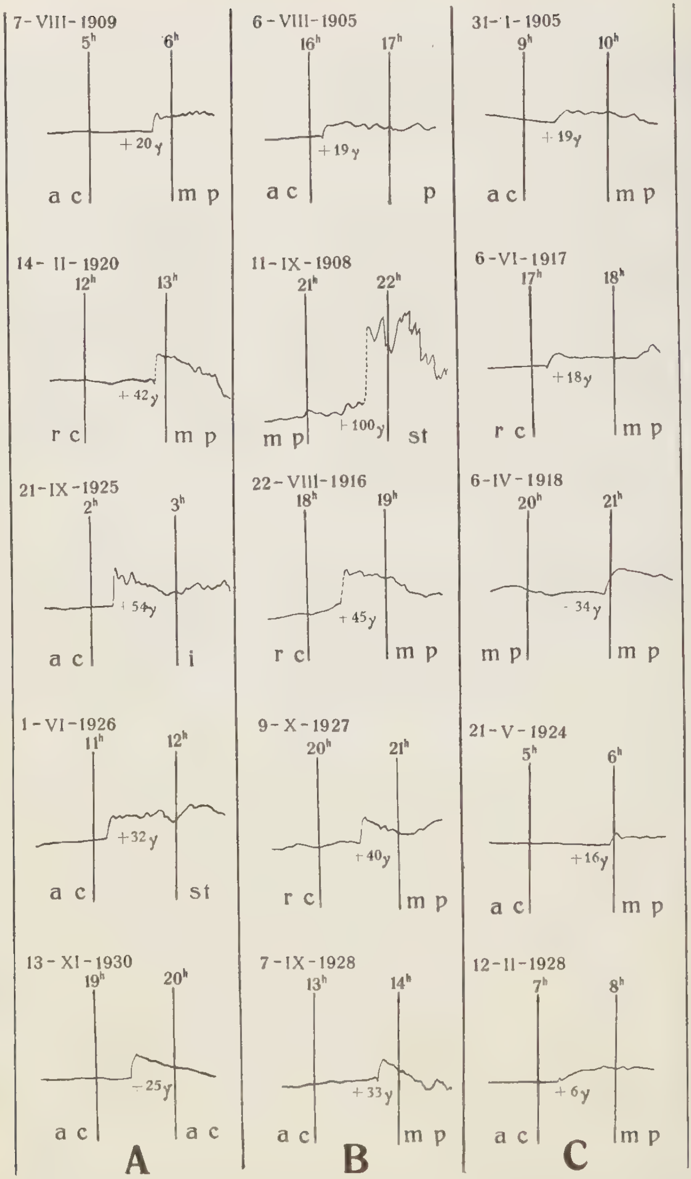


FIG. 1—*A*, *B*, y *C*: Grupos de cambios repentinos en el valor del campo magnético registrados en el Observatorio del Ebro, con curvas de calma absoluta, *ac*, calma relativa, *rc*, débil perturbación, *mp*, fuerte perturbación, *ip*, tempestad, *st* (Tiempo civil de Greenwich)

Los valores aisladamente bajos de 1928, a pesar de ser este el año de máxima actividad solar en el registro de sus diversas manifestaciones, son notables porque la baja se refleja asimismo en la curva de la amplitud

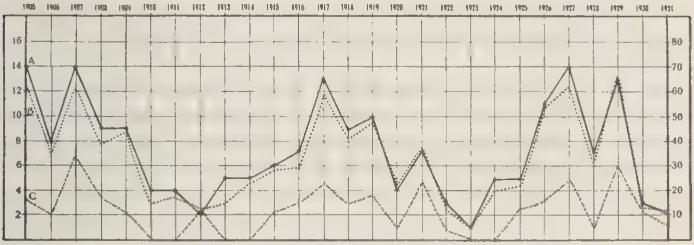


FIG. 2—Frecuencia secular en los saltos bruscos registrados en el Observatorio del Ebro —*A*, todos los saltos bruscos no ponderados, *B*, los mismos saltos ponderados, *C*, los saltos de primera categoría con su correspondiente peso

media anual de la oscilación diurna en D durante los días de calma, que muestra también una pequeña disminución aislada para el mismo año.[1]

Creemos que el carácter de la curva sugiere más bien el encuentro de nubes de partículas eléctricas a lo largo de la eclíptica durante la revolución de la Tierra alrededor del Sol, que no un influjo directo e inmediato de las manchas sobre nuestro planeta.

La curva de la distribución anual presenta dos máximos bien definidos (Fig. 3*A*) que coinciden sensiblemente con las fechas de máxima latitud heliocéntrica de la Tierra o, como parece haber demostrado J. Bartels[2], con las fechas del equinoccio, de conformidad con los resultados ya obtenidos en el registro de otras repercusiones de la actividad solar sobre el magnetismo terrestre.

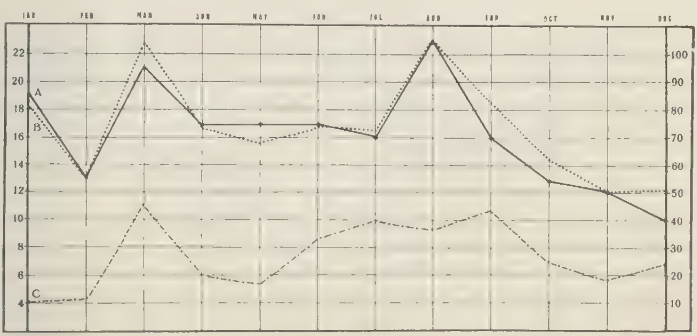


FIG. 3—Frecuencia anual en los saltos bruscos registrados en el Observatorio del Ebro —*A*, *B*, y *C* como en la Figura 1

Si sólo se tienen en cuenta los 54 saltos de primera categoría con el peso que les corresponde según el criterio arriba expuesto, la curva

[1] El único índice de la actividad solar que refleja esta disminución en 1928 es el propuesto por este Observatorio del Ebro y que consiste en la frecuencia relativa con que los flocculi se manifiestan en forma de manchas.

[2] Terr. Mag., **32**, 127-131 (1927); **37**, 1-52 (1932).

B señala un exceso bien definido de saltos bruscos durante los meses de verano para el hemisferio norte que arguye una acción diferencial, dependiente de la posición del planeta, en los efectos de la actividad solar sobre el mismo.

Esta acción diferencial debida a la posición de nuestro planeta aparece mucho más marcada en las curvas de la frecuencia diurna *A*, *B*, y *C* de la Figura 4. La curva *A* ha sido obtenida con todos los saltos bruscos registrados en 27 años dando a cada uno el mismo peso; la curva *B* con los mismos saltos bruscos ponderados; y la curva *C* con sólo los 54 saltos de primera categoría con su correspondiente peso. Aparte las irregularidades debidas al todavía escaso número dé años considerados, es bien patente en las curvas *A* y *B* un mínimo alrededor de las 8^h (T. c. Gr.) y un máximo alrededor de las 21^h; este máximo y este mínimo, si bien subsisten aún en la curva *C*, son mucho menos conspicuos que en las dos curvas anteriores.

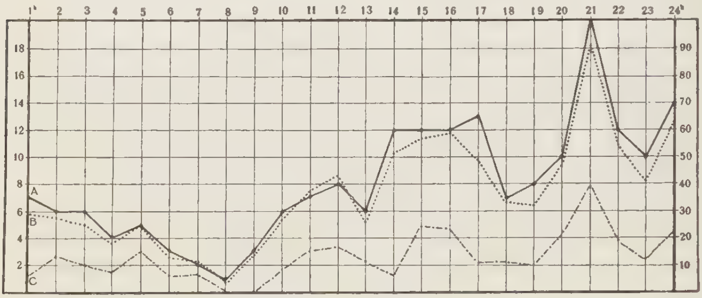


FIG. 4—Frecuencia diurna en los saltos bruscos registrados en el Observatorio del Ebro —*A*, *B*, y *C* como en las Figuras 2 y 3

Es evidente que si los saltos bruscos de los imanes reflejasen un cambio en la intensidad del campo magnético terrestre que se extendiese a todo el planeta no habría hora local favorecida en la frecuencia de los mismos; por esta razón la curva *C*, obtenida con los saltos de primera categoría que en su mayor parte corresponden a tempestades magnéticas registrados en todo el globo, apenas muestra la oscilación diurna, mientras que ésta aparece con toda distinción en las curvas *A* y *B* integradas por todos los saltos registrados durante los últimos 27 años.

Esto demuestra la existencia de cambios bruscos de alcance (range) puramente local cuya frecuencia depende de la posción del observador con respecto al Sol; de nuestras gráficas se desprende un mínimum de saltos bruscos durante las horas en que el meridiano local va a la delantera con respecto al movimiento orbital de la Tierra; un aumento progresivo durante el día local hasta las 16^h o 17^h; un mínimo secundario, pero bien definido, alrededor de las 18^h y 19^h, cuando el meridiano local queda a la espalda con respecto a la traslación del planeta; y un máximo muy pronunciado y que constituye la nota saliente de la curva a las 21^h.

Si estos saltos bruscos de carácter local obedecen al encuentro de nubes de partículas eléctricas de orígen solar, hay que reconocer que en general éstas se precipitan sobre nuestro planeta más bien en su hemisferio posterior que no en el anterior, atendido el movimiento de traslación;

esto favorecería la teoría sostenida por Chapman en contraposición a la defendida por el autor de estas líneas[3], dejando, no obstante sin explicación el mínimo de las 18^h. En general los hechos, y principalmente el máximo, se explican mejor dentro de la teoría elaborada por el mismo Chapman en colaboración con V. C. A. Ferraro[4].

Teniendo en cuenta la posición del polo magnético norte, unos 95° W, vemos que el mínimo secundario coincide con el paso de dicho polo por delante del Sol y el máximo absoluto se registra cuando el meridiano que contiene dicho polo forma un ángulo de unos 45° con la línea Sol-Tierra.

En general la forma de las curvas A y B de la Figura 3, sugiere la existencia de posiciones del meridiano local protegidas contra las causas perturbadoras y otras, en cambio, especialmente expuestas a las mismas; la posición más protegida del meridiano local sería la que tiene éste cuatro o cinco horas antes de pasar por delante del Sol, y la más expuesta la que tiene sieta horas después de dicho tránsito.

Creemos que un estudio semejante en las gráficas de otros observatorios contribuiría eficazmente a afianzar las conclusiones de esta nota y proporcionaría nuevos materiales para la teoría de las auroras polares, tan brillantemente desarrollada en nuestros días gracias a los esfuerzos de Birkeland y de Störmer[5].

[3]Terr. Mag., **27**, 161-166 (1922).

[4]Terr. Mag., **36**, 77-97 (1931).

[5]Terr. Mag., **35**, 193-208 (1930): Les aurores boréales, Conférence faite à la Sorbonne le 14 décembre 1923.

OBSERVATORIO DEL EBRO,
Tortosa, España

NOTES

(See also pages 267, 290, and 316)

21. *International Congress of Electricity, Paris, 1932*—The second International Congress of Electricity, organized by the Société Française des Electriciens, Société Française de Physique, Comité Electrotechnique Français, and Union des Syndicats de l'Electricité, under the auspices of the Commission Electrotechnique Internationale, took place in Paris, July 4 to 12, 1932. The Congress consisted of thirteen sections, of which the Eleventh Section was concerned with atmospheric electricity and terrestrial magnetism. The reports and communications presented to this Section bear on subjects of especial interest to the readers of this JOURNAL. We are, accordingly, giving below a list of the titles of the preliminary papers, distributed at the meetings, which will appear in their final form in the proceedings of the Congress. Ch. Maurain, Le développement des études de magnétisme et électricité terrestres; L. Eblé, Le champ magnétique terrestre; Ch. Maurain, Perturbations magnétiques, aurores polaires; G. Grenet, Le champ électrique terrestre; Ed. Salles, Conductibilité et ionisation de l'atmosphère; E. Mathias, L'éclair; C. Dauzère, Les décharges électriques atmosphériques; H. Norinder, Recherches oscillographiques sur le mécanisme de décharge des éclairs; E. Rothé, Les méthodes électro-magnétiques pour l'étude du sous-sol; M. et Mme. H. Labrouste, Recherches des composantes périodiques en magnétisme et électricité terrestres; J. A. Fleming, Distribution à travers le monde des observatoires magnétiques et des stations pour l'étude de la variation séculaire; O. H. Gish, Les courants électriques naturels de l'écorce de la Terre et leur rapport avec le magnétisme

terrestre; J. Bartels, L'activité du magnétisme terrestre et ses relations avec les phénomènes solaires; W. J. Rooney, Mesures de la résistivité de la Terre et leur application à la géophysique et aux problèmes techniques; G. R. Wait et O. W. Torreson, Quelques facteurs affectant la conductibilité électrique de l'atmosphère; L. Bogoiavlensky et M. Chatelain, Sur l'influence de quelques facteurs géophysiques sur les points de chute de la foudre; H. F. Johnston et A. G. McNish, Variations du champ magnétique terrestre aux observatoires de Watheroo et de Huancayo et leurs relations avec les systèmes de courants à l'intérieur et au voisinage de la Terre.; E. Stenz, Le levé magnétique des Karpates de Skole et de leur avant-pays; W. Smosarski, Sur l'exactitude des mesures du champ électrique et de la conductibilité de l'air et sur les corrections d'isolement d'après les observations visuelles.

22. *Magnetic Survey of Austria*—During the years 1928 and 1929, a new magnetic survey of Austria has been carried out and publication of the results by the Zentralanstalt für Meteorologie und Geodynamik, of Vienna, has been begun. The results of the observations are being reduced to the epoch 1930.0. The two previous surveys of Austria were made by Kreil and Liznar and apply to epochs 1850.0 and 1890.0, respectively. Thus an interval of 40 years intervenes between the different successive surveys. As the base-station for the last survey, a magnetic observatory was established at Auhof bei Wien which, unfortunately, is distant only three km from the city electric-tram system and some slight effects from this source are perceptible on the registrations. The results obtained at this Observatory, which has the distinction of being the most southeasterly one in Europe, have not been published, but data are being sent regularly to Dr. van Dijk in De Bilt for inclusion in the "Caractère magnétique de chaque jour."

23. *Aurora australis, May 29-30, 1932*—We have received a letter from Dr. Edward Kidson, director of the Meteorological Branch, Department of Science and Industrial Research, Wellington, New Zealand, from which we quote the following: "One of our observers in the south central part of the South Island of New Zealand reports having seen a brilliant aurora on the night of the 29-30th May. I understand that the Telegraph Department experienced much trouble on the next day from currents induced in their lines and that normal conditions were not restored for a day or two."

24. *Exhibition of "Aeroarctic"*—An exposition will be opened on October 28, 1932, under the auspices of "Aeroarctic," in one of the buildings of the Technische Hochschule, Berlin-Charlottenburg, and will continue for 10 to 14 days. Instruments and apparatus for use in polar exploration by means of the aircraft, and particularly in connection with the *Graf-Zeppelin*, will be on exhibition. In addition, one room will be devoted to general polar equipment, sledges, boats, clothing, provisions, portable radio-station, etc. It is also planned to hold lectures on pertinent subjects during the exhibition.

DIE MAGNETISIERUNG DER ERDE NACH DER GEOMAGNETISCHEN KONSTANTEN DER OBSERVATORIEN

Von A. Nippoldt

Louis Agricola Bauer hat im Jahre 1914 eine neue Grösse in die erdmagnetische Forschung eingeführt, die "Lokale Geomagnetische Konstante."[1] Er benutzte sie in der Hauptsache, um aus ihren Variationen in der Zeit den Zusammenhang erdmagnetischer Veränderungen mit der Sonnentätigkeit zu prüfen. In folgenden Zeilen soll dargetan werden, dass diese Grösse auch geeignet ist, um etwas über die *räumliche* Verteilung der Magnetisierung der Erde auszusagen.

Die Anzahl der erdmagnetischen Observatorien ist zu einer genügend ausreichenden Erledigung der verschiedenen Fragen, allerdings noch nicht gross genug; es sind daher längst Rechnungen in grösserem Umfang eingeleitet worden, über die dann später noch einmal im Zusammenhang zu berichten ist. Aber die besondere Bedeutung der Observatorien als das feste Gerüst für alle magnetischen Vermessungen macht eine nur für *sie* durchgeführte Studie doch wertvoll genug, um sie hier bekannt zu geben.

In der bekannten formalen Darstellung des Potentials V eines magnetischen Feldes durch eine unendliche Reihe von Kugelfunktionen $P^{n,m}$

$$V = \sum_{1}^{\infty} \sum_{0}^{n} m\, r^{-n-1} P^{n,m} (\cos u)\, (M^{n,m} \cos n\lambda + N^{n,m} \sin n\lambda) \qquad (1)$$

hängt die Grösse der Koeffizienten $M^{n,m}$, $N^{n,m}$ ausser von den Zahlwerten des Potentials an den Stellen r, u, λ des Raums noch von der Lage des Koordinatensystems ab. Wählt man verschiedene Lagen aus, so zeigt sich, dass drei Koeffizienten, nämlich $M^{0,1}$, $M^{1,1}$, $N^{1,1}$ eine besondere Stellung einnehmen, indem der Ausdruck

$$[(M^{0,1})^2 + (M^{1,1})^2 + (N^{1,1})^2]^{1/2} r^3 \qquad (2)$$

stets gleich gross ausfällt. Er ist demnach gegen Koordinaten-Transformationen invariant. Daraus geht hervor, dass sein Auftreten keine Eigenschaft der formalen Behandlungsweise sein kann, sondern mit dem magnetischen Feld als einer physikalischen Vorstellung verbunden ist. Trotzdem stehen dem Begriff "Magnetisches Moment," wie Gauss unsere Invariante benennt, noch grosse Schwierigkeiten entgegen, wenn man als praktisches Ziel jeder Forschung die "Erklärung" eines Naturvorgangs ansieht.

Das magnetische Moment ist eine hyperbolische Verbindung zwischen einer Länge und einer Magnetisierung, sodass es unendlich viele Wertepaare ergibt, die alle dasselbe Moment äussern; das macht das Moment zu einem schlechten Mittel zur "Erklärung" physikalischer Felder; seine Bedeutung ist damit erschöpft, dass es sie rechnerisch beherrscht.

Die lokale magnetische Konstante ist zur Erklärung geeigneter weil sie nur durch einen Zahlfaktor mit nur einer einzigen anderen physikalischen Grösse verbunden ist, der erklärungstechnisch einfachen räumlichen Magnetisierung, indem

$$G = (4/3)\, \pi\, \rho \qquad (3)$$

[1] Terr. Mag., **19**, 113-125 (1914).

Unsere Invariante ist identisch mit dem Glied erster Ordnung der Darstellung durch Kugelfunktionen, das für die Erdoberfläche ($r = 1$) gewöhnlich geschrieben wird

$$V_n = g_1^0 \cos u + g_1^1 \sin u \cos \lambda + h_1^1 \sin u \sin \lambda \qquad (4)$$

worin wir jetzt von den Bezeichnungen MN auf die bei uns üblichen gh übergehen, und sich ihre Zahlwerte auf den Erdmittelpunkt als Koordinaten-Nullpunkt und die X-Achse parallel der Rotationsachse der Erde beziehen. Es wird dann

$$M = \sqrt{(g_1^0)^2 + (g_1^1)^2 + (h_1^1)^2} \times R^3 \qquad (5)$$

wo R den Radius der Erde bezeichnet.

L. A. Bauer hat nun von dem Gesamtfeld der Erde das erste Glied abgezogen und so ein von ihm als "Ueberbleibendes Feld" bezeichnetes magnetisches Erdfeld gebildet. Es ist durchaus kein regellos gestaltetes, sondern steht offenbar in Verbindung mit dem Grossaufbau des Erdkörpers.[2]

Der Wunsch, dieses Feld leichter und rascher für verschiedene Zeiten ableiten zu können, ohne erst jedesmal Entwicklungen nach Kugelfunktionsreihen vorzunehmen, war die Anregung zu nachfolgender Studie.

Bauer hat an der eingangs zitierten Stelle gezeigt, dass der Faktor von R^3 in der Formel (5) bei einem inneren Felde sich aus den Komponenten des Erdfelds berechnen lässt nach

$$\sqrt{(g_1^1)^2 + (g_1^1)^2 + (h_1^1)^2} = \sqrt{X^2 + Y^2 + (Z/2)^2} = G \qquad (6)$$

Er setzt ihn einer neuen Grösse gleich, eben der "Lokalen erdmagnetischen Konstante G."

Gegenüber der seitherigen Methode, die Volummagnetisierung ρ durch die rechnerische Ermittlung der drei ersten Kugelfunktionskoeffizienten g_1^0, g_1^1, h_1^1 zu erhalten, ist die Ableitung von G durch eine ganz einfache und kurze Rechnung zu erzielen. Natürlich beruht der aus einem Ort ermittelte Wert von G auf den an diesem Ort zu der Zeit gerade vorhandenen Werten von X, Y, Z; daher der Zusatz "lokal" in der Bezeichnung von G. Es enthält ausserdem den Einfluss der anomalen Magnetisierung an dem Orte. Benutzt man viele Orte, so wächst die Wahrscheinlichkeit, dass bei geeigneter Verteilung über die ganze Erde der Mittelwert dem aus g_1^0, g_1^1, h_1^1 direkt abgeleiteten Werte der Erdmagnetisierung gut entspricht. Es sei vorausbemerkt, dass dies für das hier behandelte Material aller magnetischen Observatorien der Erde der Fall ist.

Hat man aber den Mittelwert in dieser Weise gesichert, so geben die Unterschiede der Einzelwerte gegen ihn ein Maass für die lokale Magnetisierung ab, d.h. sie liefern das Ueberbleibende Feld.

Eine weitere Möglichkeit der Anwendung von G sei noch erwähnt, obwohl von ihr in vorliegender Arbeit kein Gebrauch gemacht wurde. Berechnet man für nah beieinander liegende Punkte G, so erhält man die Verteilung der Magnetisierung für diese beschränkte Region. G leistet dann dasselbe, was die Ermittelung der äquivalenten Oberflächenbelegung leistet, nur dass diese für einigermassen ausgedehnte Bereiche ausser der Vertikalintensität noch den Wert des Potentials an allen Orten gebraucht, der rechnerische Mühe macht.

[2]Terr. Mag., **4**, 33-58 (1899); **5**, 1-4 (1900).

Im Ganzen kann man sagen, dass die Hauptvorzüge der Grösse G weniger im alten Sinne theoretische, als praktische sind.

Das hier behandelte Material besteht aus den Daten der erdmagnetischen Observatorien, da sie die Stellen bester Werte sind. Es wurden die beiden Epochen 1910.5 und 1920.5 der Rechnung unterzogen. Aus ersterem Jahre liegen 50, aus letzterem 44 Werte vor.

Die von Bauer gegebene Formel für die Berechnung von G erhielt folgende Umwandlung. Setzt man in Formel (6) $Z = H\ tg\ I$ so erhält man nach einfachen Umformungen

$$G = (H \sqrt{4 + tg^2 I})/2$$

Da nun $$\sqrt{1 + tg^2 I} = \sec I$$

so findet sich $$G = (H \sqrt{\sec^2 I + 3})/2 \qquad (7)$$

was die logarithmisch unbequeme Bildung von Quadratsummen vermeidet.

Der Faktor von H in (7) schwankt zwischen $I = 0°$ bis $75°$ nur zwischen 1 und 2; zur Kontrolle kann man auch nach der alten Formel arbeiten.

Die Tabelle bringt ausser dem Namen des Observatoriums seine geographischen-Koordinaten und nun die Werte der Konstanten G für die beiden Epochen 1910 und 1920; . . . . . bedeutet, dass aus diesem Jahre keine Beobachtungen vorliegen. Die Bedeutung der übrigen Spalten lernen wir noch kennen.

Ein erster Ueberblick über die Zahlen für G zeigt, dass geographisch benachbarte Orte auch annähernd gleiche Beträge für G ergeben. Daraus schliessen wir, dass die lokale Magnetisierung nach allgemein terrestrischen Belangen verteilt und kein Zufallsergebnis ist. Die Werte schwanken 1910 zwischen 0.2450 für Sankt-Paul de Loanda und 0.3967 für Toungoo, 1920 von 0.2473 Vassouras bis 0.4000 wieder für Toungoo im Mittel um 48% des Mittelwerts der Erde. Es wäre also ganz schon verfehlt, aus dem G-Werte eines einzigen Observatoriums auf das magnetische Moment der Erde zu schliessen.

Offenbar wäre das nur erlaubt, wenn der lokale Unterschied des betreffenden Observatoriums gegen den für die ganze Erde gültigen Wert durch alle Epochen konstant wäre. Es sei gern gestanden, dass dies eigentlich erwartet wurde. In den Spalten (7) und (8) unserer Tabelle sind die örtlichen Unterschiede gegen das jeweilige Mittel aller Observatorien enthalten. Es war das 1910 der Wert 0.3191 und 1920, 0.3165. Die letzte Spalte (9) enthält die Differenzen zwischen diesen beiden Epochalwerten in 0.1 Milligauss. Man sieht ohne weiteres, dass von einer Konstanz des örtlichen Unterschieds nicht die Rede sein kann. Die Erklärung hierfür findet sich weiter unten.

Um den ersten Zweck der Untersuchung zu prüfen, in wie weit die G-Zahlen mit dem überbleibenden Felde Bauer's zusammenhängen, sind die lokalen Unterschiede für beide Epochen zunächst einmal in Mittel zusammengezogen und in eine Karte eingetragen worden (Fig. 1). Es findet sich, dass alle Zahlen sich übersichtlich gruppieren; die geographisch bedingte Anordnung wird ganz klar. Eine unmittelbare Beziehung zu der Lage der Festländer und Meere ergiebt sich nicht; um so ausgesprochener ist der Zusammenhang mit Bauer's überbleibendem Felde. Es sind daher in unsere Karte die Hauptpole dieses Feldes durch Kreuze gekennzeichnet.

Tabelle 1—*Lokale magnetische Konstante G für die neueren Observatorien*

(1) Nr. Name	(2) ϕ	(3) λ	(4) G_{1910}	(5) G_{1920}	(6) $\Delta 1$ $\times 10^4$	(7) ΔG_{1910}	(8) ΔG_{1920}	(9) $\Delta 2$ $\times 10^4$
	° ′	° ′						
1 Sodankylä	67 22	26 39	....	0.2765	.....	....	−0.0400	.....
2 Pavlovsk	59 41	30 29	0.2862	0.2837	−25	−0.0329	−0.0328	− 1
3 Sitka	57 03	224 40	0.3218	0.3189	−29	+0.0027	+0.0024	+ 3
4 Katharinenburg	56 50	60 38	0.3083	0.3048	−35	−0.0108	−0.0117	+ 9
5 Rude Skov	55 51	12 27	0.2829	0.2811	−18	−0.0362	−0.0354	− 8
6 Kazan, alt	55 47	49 08	0.2988	....	.....	−0.0203	....	.....
7 Kazan, neu	55 50	48 51	....	0.2958	.....	....	−0.0207	.....
8 Eskdalemuir	55 19	356 48	0.2824	0.2806	−18	−0.0367	−0.0359	− 8
9 Meanook	54 37	246 39	....	0.3282	.....	....	+0.0117	.....
10 Stonyhurst	53 51	357 32	0.2831	0.2816	−15	−0.0360	−0.0349	−11
11 Wilhelmshaven	53 32	8 09	0.2842	....	.....	−0.0349	....	.....
12/13 Potsdam-Seddin	52 23	13 02	0.2857	0.2841	−16	−0.0334	−0.0324	−10
14 Irkutsk, alt	52 16	104 19	0.3443	....	.....	+0.0252	....	.....
15 Irkutsk, neu	52 28	104 02	....	0.3413	.....	....	+0.0248	.....
16 De Bilt	52 06	5 11	0.2847	0.2832	−15	−0.0344	−0.0333	−11
17 Valencia	51 56	349 45	0.2866	0.2846	−20	−0.0325	−0.0319	− 6
18/19 Kew-Greenwich	51 28	359 46	0.2857	0.2842	−15	−0.0334	−0.0323	−11
20 Uccle	50 48	4 21	0.2862	....	.....	−0.0329	....	.....
21 Falmouth	50 09	354 56	0.2864	....	.....	−0.0327	....	.....
22 Val-Joyeux	48 49	2 01	0.2874	0.2862	−12	−0.0317	−0.0303	−14
23 München	48 09	11 37	0.2900	....	.....	−0.0291	....	.....
24 O'Gyalla	47 53	18 12	0.2924	....	.....	−0.0267	....	.....
25 Odessa	46 26	30 46	0.3007	....	.....	−0.0184	....	.....
26 Pola	44 52	13 51	0.2940	....	.....	−0.0251	....	.....
27 Agincourt	43 47	280 44	0.3375	0.3313	−62	+0.0184	+0.0148	+36
28 Tiflis, alt	41 43	44 48	0.3180	....	.....	−0.0011	....	.....
29 Capodimonte	40 52	14 15	0.3015	....	.....	−0.0176	....	.....
30 Tortosa	40 49	0 30	0.2976	0.2968	− 8	−0.0215	−0.0197	−18
31 Coimbra	40 12	351 35	0.2982	0.2974	− 8	−0.0209	−0.0191	−18
32 Baldwin	38 47	264 50	0.3535	....	.....	+0.0344	....	.....
33 Cheltenham	38 44	283 10	0.3438	0.3361	−77	+0.0247	+0.0196	+51
34 San Miguel	37 46	334 21	....	0.3082	.....	....	−0.0083	.....
35 San Fernando	36 28	353 48	0.3043	0.3029	−14	−0.0148	−0.0136	−12
36 Tsingtau	36 04	120 19	....	0.3663	.....	....	+0.0498	.....
37 Tokio	35 41	139 45	0.3465	....	.....	+0.0274	....	.....
38 Tucson	32 15	249 10	....	0.3527	.....	....	+0.0362	.....
39 Zikawei	31 12	121 26	0.3729	....	.....	+0.0538	....	.....
40 Lukiapang	31 19	121 02	....	0.3723	.....	....	+0.0558	.....
41 Dehra Dun	30 19	78 03	0.3691	0.3684	− 7	+0.0500	+0.0519	−19
42 Helwan	29 52	31 20	0.3268	0.3270	+ 2	+0.0077	+0.0105	−28
43 Barrackpore	22 46	88 22	0.3894	....	.....	+0.0703	....	.....
44 Hongkong, alt	22 18	114 10	0.3874	0.3879	+ 5	+0.0683	+0.0714	−31
45 Honolulu	21 19	201 56	0.3156	0.3119	−37	−0.0035	−0.0046	+11
46 Toungoo	18 56	96 27	0.3967	0.4000	+33	+0.0776	+0.0835	−59
47 Colaba-Alibag	18 38	72 52	0.3771	0.3790	+19	+0.0580	+0.0625	−45
48 Vieques	18 09	294 33	0.3352	0.3283	−69	+0.0161	+0.0118	+43
49 Antipolo	14 36	121 10	0.3848	0.3850	+ 2	+0.0657	+0.0685	−28
50 Kodaikanal	10 14	77 28	0.3751	0.3782	+31	+0.0560	+0.0617	−57
51 Buitenzorg	− 6 35	106 50	0.3830	0.3854	+24	+0.0639	+0.0689	−50
52 St. Paul de Loanda	− 8 48	13 13	0.2450	....	.....	−0.0741	....	.....
53 Samoa	−13 48	188 14	0.3695	0.3672	−23	+0.0504	+0.0507	− 3
54 Tananarivo	−18 55	47 32	0.2777	....	.....	−0.0414	....	.....
55 Mauritius	−20 06	57 33	0.2818	0.2761	−57	−0.0373	−0.0404	+31
56 La Quiaca	−22 08	294 17	....	0.2679	.....	....	−0.0486	.....
57 Vassouras	−22 24	316 21	....	0.2473	.....	....	−0.0692	.....
58 Watheroo	−30 19	115 53	....	0.3557	.....	....	+0.0392	.....
59 Pilar	−31 40	296 07	0.2644	0.2602	−42	−0.0547	−0.0563	+16
60 Melbourne	−37 32	145 28	....	0.3631	.....	....	+0.0466	.....
61 Christchurch	−43 32	172 37	0.3573	0.3558	−15	+0.0382	+0.0393	−11
62 Neu-Jahr-Insel	−54 39	295 51	0.3145	....	.....	−0.0046	....	.....

N bezeichnet wie bei Bauer einen das Nordende der Nadel anziehenden, S einen es abstossenden Magnetismus. Dem Bauer'schen über China gelegenen Pol N_1 bei $\phi = 35° N$, $\lambda = 110°$ entspricht ein positiver Pol in $\triangle G$ bei $\phi = 25° N$, $\lambda = 100°$. G erreicht um ihn die höchsten Werte bis + 80 (Intensität bei Bauer + 139). Für den stärksten Pol N_2 fehlt es an Werten für $\triangle G$; er liegt bei $\phi = 50° S$, $\lambda = 325°$. N_3 liegt bei $\phi = 42° N$, $\lambda = 268°$ im Gebiet der grossen nordamerikanischen Seen; ihm liegt sehr nahe bei $\phi = 35° N$, $\lambda = 260°$ ein Pol von $\triangle G$; die Intensitäten sind + 84, bezugsweise + 40 Milligauss. Von den S-Polen ist in der $\triangle G$-Karte S_1'' am besten zu erkennen, weil er im Norden von Europa seinen Kern hat, und dieser Erdteil fast ganz unter seinem Einfluss steht. S_1'' liegt nach Bauer unter 60° Breite und 0° Länge, doch ist die Breitenlage wahrscheinlich nördlicher wie die Karten- und Rechengrenze von Bauer erkennen lässt. Jedenfalls sprechen die $\triangle G$-Zahlen für einen nördlicher liegenden Kern. Das Zusammenfallen beider Pole erscheint hier am engsten. Die Intensität ist bei Bauer − 106, bei $\triangle G$ − 40. S_1 hat einen zweiten Pol S_1' nach Bauer bei $\phi = 0°$, $\lambda = 20°$ mit der Intensität − 124. In seiner Nähe liegt die vereinzelte Station Sankt-Paul de Loanda mit $\triangle G = -74$; die nächsten sind Mauritius und Tananarivo, deren Werte so sind, dass man um St. Paul wohl ein Minimum erwarten könnte. Der Bauer'sche Pol S_2 ist in $\triangle C$ wieder leicht zu erkennen, da er auf Australien fällt, und dort drei Observatorien zur Verfügung stehen. Er liegt in 45° S und 135° Länge, während der Pol von $\triangle G$ bei 35° S und 145° Länge zu erwarten ist. Die Intensität ist beim Residual Field −92[3], bei $\triangle G + 50$. Bei Bauer's Pol S_3 in $\phi = 45° N$, $\lambda = 182°$ bei den Aleuten fehlt es wieder an entgegen zu stellenden Werten von $\triangle G$.

Zeigt sich somit ein recht enger Zusammenhang der beiden Karten, so muss doch erwähnt werden, das bei $\triangle G$ noch ein Pol S_1''' auftritt, der ungefähr in $\phi = -22°$, $\lambda = 316°$ zu liegen kommt, das ist hart an der Küste von Südamerika, der in Bauer's Originalkarte kein Gegenstück findet, wohl aber aus seinen Zahlen hervorgeht. Es ist ein Nebenpol in − 20° Breite und 340° Länge, das ist ungefähr bei Sankt-Helena. Ist die Verschiebung nach Osten auch verhältnismässig gross, so weist doch das Auftreten des Nebenpols, dessen Intensität − 61 gegen − 69 in $\triangle G$, darauf hin, dass auch dieser neue Pol durch das Ueberbleibende Feld belegt werden kann.

$\triangle G$ ist positiv, wenn G grösser ist als der für die ganze Erde gültige Wert, d.h. wenn die lokale Magnetisierung stärker ist als die mittlere der Erde. Stellen wir zusammen, so finden wir für beide Felder folgende Uebersicht:

Z-Pol	ϕ	λ	Int.	G-Pol	ϕ	λ	Int.
N_1	35°N	110°	+139	N_1	25°N	100°	+80
S_1'	0N	20	−124	S_1'	(10S	33	−74)
S_1''	60N	0	−106	S_1''	65N	10	−40
N_2	50S	325	+164	N_2	....	....	....
S_2	45S	135	−92	S_2	35S	145	+50
S_1'''	20S	340	−61	S_1'''	22S	316	−69
N_3	42N	268	+84	N_3	35N	260	+40

[3]Anm. In der Tabelle IV, Terr. Mag., **4**, 45, ist sie irrtümlich mit −0.1338 Gauss angegeben, was nicht mit der Zahlentabelle S. 43 übereinstimmt. Richtig ist −0.0921. Auch die Länge des Pols S_3 ist nicht 125°, sondern 182°.

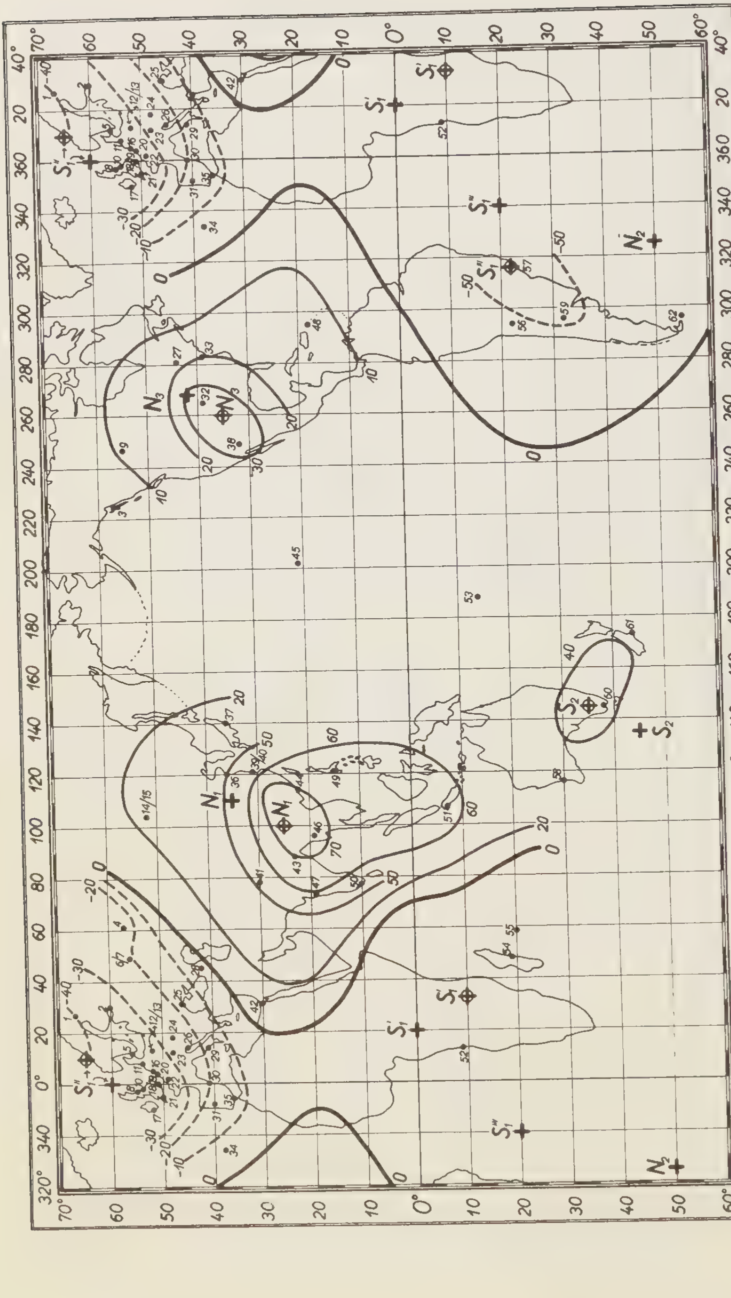


Fig. 1—Verteilung der lokalen Magnetisierung "G"

(Kreuze = Pole des Residual Field; Kreuze in einem Kreise = Pole der Magnetisierung G; Einheit der Zahlen an den Kurven 0.001 Gauss; Ziffern an den Punkten = Nummer der Observatorien in der Tabelle)

Die Intensitäten dürfen grundsätzlich nicht quantitativ verglichen werden, denn in der linken Seite geht nur Z ein, die Vertikalintensität, in der rechten auch die horizontale H. Nur die Vorzeichen müssen übereinstimmen, und hier fällt es auf, dass das bei S_2 nicht der Fall ist. Vermutlich liegt dies daran, dass für Bauer in der Gegend von Australien noch nicht die guten Beobachtungswerte vorlagen, die jetzt durch die drei Observatorien Watheroo, Melbourne, und Christchurch gegeben sind.

Abgesehen von dieser räumlich beschränkten Diskrepanz kann man als Ergebnis dieses hier durchgeführten Vergleichs feststellen, *die geographische Verteilung der geomagnetischen Konstanten geht parallel mit dem Ueberbleibenden Feld von Bauer.*

Demnach ist in der Tat die Hoffnung berechtigt, die rasch und einfach, nur aus den Beobachtungen der Stationen zu findenden Zahlen der geomagnetischen Konstanten immer wieder neu zu erhalten, und als ein brauchbares Maass über die Gesetze der Erdmagnetisierung zu verwenden. Ein weiterer, von dem Verfasser auch schon in Angriff genommener Weg ist es, die immerhin spärlichen Zahlen der Observatorien nur als eine Art von festem Gerüst für Zahlen über besser verteilte Stationen zu benützen.

Beachten wir nunmehr die Differenzen der G-Werte zwischen den beiden Epochen, so haben wir schon festgestellt, dass sie innerhalb der zehn Jahre nicht konstant geblieben sind. Die entsprechenden Zahlen stehen in unserer Tabelle unter $\triangle 1$ in der 6. Spalte. Trägt man sie gleichfalls in ein Kartennetz ein, so findet sich, dass sie ebenfalls geographisch geordnet sind, es sind keine Zufallszahlen. Es lässt sich ein geschlossenes Gebiet anwachsender Magnetisierung der Erde feststellen, das zwischen Südasien und Ostafrika liegt und mit dem südmagnetischen Pol N_1 nahe zusammenfällt. Alle anderen Orte sind abnehmend, doch ist das Netz der Observatorien zu dünn, um hier irgendwelche Zentra zu finden. Das Ueberwiegen der negativen Zahlen rührt von der tatsächlichen Abnahme der Erdmagnetisierung her. Sie beträgt nach den vorhandenen Kugelfunktionsentwicklungen von 1910 bis 1920, 26 E.d.4. St. Das Mittel der 32 Observatorien giebt $-$ 17, wobei aber das übermässig dichte Netz von Europa zu stark zur Geltung kommt.

Dies scheidet bei den Differenzen $\triangle 2$ Spalte 9 aus, da sie die Unterschiede sind zwischen den Abweichungen der G gegen den für die Epoche geltenden Normalwert der Erde. Von vornherein wurde erwartet, dass die lokalen Unterschiede gegen das jeweilige homogene Feld konstant seien. Die Uebersicht der Zahlen erweist aber, dass sie sich nicht rein zufällig gruppieren, sondern wiederum nach geographischen Gesichtspunkten.

Wir schliessen daraus, dass *die Säkularvariation nicht nur das quasi-homogene Feld, sondern auch das überbleibende betrifft.*

Andere Untersuchungen, die hier nur erwähnt werden können, haben inzwischen dargetan, dass die regionalen Störungsfelder des Residual Field sogar sehr viel grössere Säkularvariationen besitzen und vornehmlich das europäische als die Erde im Ganzen. *Was wir als Säkularvariation des quasi-homogenen Felds seither berechnet haben, ist nichts anderes als die Resultante der entsprechenden Veränderungen aller Teilmagnetisierungen.*

Es ist nicht so, dass das homogene Feld die Säkularvariation allein trägt, und das überbleibende Störungsfeld konstant bleibt.

Diese neue Einsicht in das Wesen der Säkularvariation zeigt, dass es

irdische Vorgänge sein müssen, welche hier wirksam sind. Die Magnetisierung der Erdkruste wird in—geologisch betrachtet—rapider Schnelligkeit geändert.

Das soll nicht besagen, dass diese innere Ummagnetisierung nicht auch mit ausserirdischen Vorgängen in Beziehung steht, wobei vor allem an Vorgänge im Ringstrom der Erde zu denken ist, allein hier erheben sich gewichtige Bedenken theoretischer Natur, die erst zu überwinden sind.

Auf jeden Fall müssen wir uns davon frei machen, die Säkularvariation des homogenen Feldes als die einzige Ursache der Ummagnetisierung auch der Teilfelder der Erdkruste anzusehen. Viel wahrscheinlicher ist, dass die Ummagnetisierung der Erdkrustenteile die Quelle der Säkularvariation des homogenen Feldes ist. Nur wenn tatsächlich, unabhängig von der Magnetisierung der Erdkruste noch ein wahres homogenes magnetisches Feld existiert, kann dies auch eine selbständige Säkularvariation besitzen.

Für alle solche Untersuchungen giebt es keine besser geeignete Grösse als die lokale magnetische Konstante von Bauer.

Meteorologisch-Magnetisches Observatorium,
Potsdam, Deutschland

NOTE ON THE MAGNETIC POTENTIAL AT THE GEOGRAPHIC POLE

By L. Steiner

In the following the general formulæ are developed to calculate the magnetic potential of the permanent field at the geographic pole from the horizontal components of the magnetic force on the surface—a subject in which our lamented colleague Bauer was greatly interested.

If V is the potential of the permanent field of terrestrial magnetism and X, Y, and Z are the components of magnetic force towards geographic north, east, and vertically upwards, we have

$$X = + \frac{\partial V}{R\partial u}, \quad Y = - \frac{\partial V}{R \sin u \partial \lambda}, \quad Z = - \frac{\partial V}{\partial r} \tag{1}$$

where u is the co-latitude, λ the longitude, R the Earth's radius. From equations (1) the well known theorems follow:[1] (a) If X is known at all points of the surface, Y can be determined; and (b) if Y is known at all points of the surface and X at all points of one meridian line, or more generally at all points of a line on the surface from the north to the south geographic pole, then X can also be determined at every point.

These two very remarkable theorems are often given in text-books in the following form:[2,3] (a') The value of the potential is known at all points of the Earth's surface, if we know X at all points of the surface and the value of the potential at the geographic pole or at another point on the surface; and (b') the potential is known at all points of the surface if we know Y at all points of the surface and X at all points of one meridian line or in general at all points of any line running from the geographic north pole to the geographic south pole.

Theorem (a') may give rise to the misunderstanding that besides the values of X we must know the potential at the geographic pole (V_0), whereas, as we can easily show, from the values of the component X we can also determine V_0, provided the cause of the permanent field lies entirely within the Earth's crust. If there are also agents without the Earth's crust, one constant value—the potential of the exterior source in the centre of the Earth—remains undetermined.

From the first of equations (1) we get

$$\frac{V}{R} = \frac{V_0}{R} + \int_0^u X \mathrm{d}u \tag{2}$$

V_0 is the potential at the geographic north pole, and the integration is to be executed from $u = 0$ to the value of u on the meridian line through the point P where the potential is V.

Multiply equation (2) by the surface element $\mathrm{d}S = R^2 \sin u \, \mathrm{d}u\mathrm{d}\lambda$ of the Earth's surface and then integrate over the whole surface. We have

[1] C. F. Gauss, Allgemeine Theorie des Erdmagnetismus, §§15, 16, Werke, **5** (1839).

[2] J. C. Maxwell, A treatise on electricity and magnetism, 3d ed., **2**, 129-130 (1904).

[3] A. Gray, A treatise on magnetism and electricity, **1**, 63-64 (1898).

$$\frac{1}{R}\iint V\mathrm{d}S = 4\pi R V_0 + \iint \mathrm{d}S \int_0^u X\mathrm{d}u$$

According to a theorem of the theory of potential we can write[4]

$$\iint V\mathrm{d}S = 4\pi R\, \Sigma m + 4\pi R^2\, U$$

where Σm is the magnetic mass within the Earth and U the potential at the centre of the Earth of the external source (magnetic masses or electric currents). As $\Sigma m = 0$, we have

$$4\pi R U = 4\pi R V_0 + \iint \mathrm{d}S \int_0^u X\mathrm{d}u, \quad \text{or}$$

$$\frac{V_0}{R} = \frac{U}{R} - \frac{1}{4\pi R^2}\iint \mathrm{d}S \int_0^u X\mathrm{d}u, \text{ and}$$

$$\frac{V}{R} = \frac{U}{R} - \frac{1}{4\pi R^2}\iint \mathrm{d}S \int_0^u X\mathrm{d}u + \int_0^u X\mathrm{d}u \qquad (3)$$

Thus we see, if we know the X-component at all points of the Earth's surface, we know also the potential, provided the source of the permanent field lies entirely within the Earth's crust, and up to the constant value U, if there are also exterior agents.

We see also that if $U = 0$, we have

$$\frac{V_0}{R} = -\frac{1}{4\pi R^2}\iint \mathrm{d}S \int_0^u X\mathrm{d}u = -\frac{1}{4\pi R^2}\int_{u=0}^{\pi} R\mathrm{d}u \int_{\lambda=0}^{2\pi} R \sin u\mathrm{d}\lambda \int_0^u X\mathrm{d}u$$

The magentic potential at the north geographic pole divided by the radius of the Earth is the mean value of $\int_0^u X\mathrm{d}u$ on the surface of the Earth taken with the minus sign.

As to theorem (b') let any line (s) be drawn on the surface from the geographic north pole to the geographic south pole. If ds is the differential element of the s-line and H_s, the horizontal component of magnetic force in the direction ds, further ψ the angle between the direction of ds and the direction of X (ψ is reckoned in the direction north to east to south to west), then we have

$$-\frac{\partial V}{\partial s} = H_s \text{ and } V_{\lambda_0,u} - V_0 = -\int_{u=0}^{u} H_s\,\mathrm{d}s, \;\; H_s = X_s \cos\psi + Y_s \sin\psi$$

The integration is to be taken along the line s from the north pole to co-latitude u, where line s is being cut by the λ_0 meridian. From the second of the equations (1) we have

$$V_{\lambda,u} = V_{\lambda_0,u} - \int_{\lambda_0}^{\lambda} YR \sin u\mathrm{d}\lambda \quad \text{and}$$

$$V_{\lambda,u} = V_0 - \int_{u=0}^{u}{}_{s} (X_s \cos\psi + Y_s \sin\psi)\,\mathrm{d}s - \int_{\lambda_0}^{\lambda} YR \sin u\mathrm{d}\lambda \qquad (4)$$

[4] C. F. Gauss, Allgemeine Lehrsätze in Beziehung auf die im verkehrten Verhältnisse des Quadrats der Entfernung wirkenden Anziehungs- und Abstossungs-kräfte, §20. Werke, 5 (1839).

Let us multiply (4) by $R \sin u \, d\lambda$ and then integrate from λ to $\lambda+2\pi$, we get

$$\int_{\lambda}^{\lambda+2\pi} V_{\lambda,u} R \sin u d\lambda = 2\pi R \sin u V_0 - 2\pi R \sin u \int_{u=0}^{u}{}_{s} (X_s \cos\psi + Y_s \sin\psi) \, ds - \int_{\lambda}^{\lambda+2\pi} R \sin u d\lambda \int_{\lambda_0}^{\lambda} YR \sin u d\lambda$$

Multiplying by $R du$ and integrating from $u = 0$ to $u = \pi$, we have

$$\int_0^{\pi} R du \int_{\lambda}^{\lambda+2\pi} V_{\lambda,u} R \sin u d\lambda = 4\pi R^2 V_0 - [2\pi \int_0^{\pi} R^2 \sin u du \int_{u=0}^{u}{}_{s} (X_s \cos\psi + Y_s \sin\psi) \, ds] - \int_0^{\pi} R du \int_{\lambda}^{\lambda+2\pi} R \sin u d\lambda \int_{\lambda_0}^{\lambda} YR \sin u d\lambda \text{ or}$$

$$\iint V_{\lambda,u} dS = 4\pi R^2 U = 4\pi R^2 V_0 - 2\pi \int_0^{\pi} R^2 \sin u du \int_{u=0}^{u}{}_{s} (X_s \cos\psi + Y_s \sin\psi) \, ds - \iint dS \int_{\lambda_0}^{\lambda} YR \sin u d\lambda$$

where $dS = R^2 \sin u du d\lambda$ is a differential element of the Earth's surface. And from the last equation we get

$$\frac{V_0}{R} = \frac{U}{R} + \frac{1}{2R} \int_0^{\pi} \sin u du \int_{u=0}^{u}{}_{s} (X_s \cos\psi + Y_s \sin\psi) \, ds + \frac{1}{4\pi R^2} \iint dS \int_{\lambda_0}^{\lambda} Y \sin u d\lambda \tag{5}$$

If we put this value of V_0 into equation (4) we get $V_{\lambda,u}$ expressed by the values of Y on the surface and by X_s (and Y_s) at the points of the line s.

If we choose for s the λ_0 meridian line, then we have

$$\psi = 180^{\circ}, \cos\psi = -1, ds = R du, X_s = X_{\lambda_0}, Y_s = 0$$

and the second member on the right side of (5) takes the form

$$-\frac{1}{2} \int_0^{\pi} \sin u du \int_0^{u} X_{\lambda_0} du$$

All our deductions can of course also be verified by the mathematical expressions that give the potential and the components of magnetic force in spherical harmonics. But the integrations in equations (3), (4), and (5) can be executed also by means of mechanic quadrature if the numerical values of the force components required are known with sufficient accuracy.

Royal Hungarian Institute for Meteorology and Terrestrial Magnetism,
Budapest, Hungary

NOTES

(See also pages 267, 277, and 316)

25. *Cosmic-ray observations*—Dr. A. H. Compton in his cosmic-ray survey (see this JOURNAL, **37,** 77, 1932), with the assistance of the staff of the Huancayo Magnetic Observatory, made cosmic-ray determinations at various altitudes along the Central Railway of Peru, at the Huancayo Magnetic Observatory, and on Huaytapallacu Peak near the Observatory at an altitude of 15,000 feet. He and P. G. Ledig, Observer-in-Charge at Huancayo, then flew by airplane to Arequipa, where observations were made both at the level of the city (about 7,500 feet) and on El Misti first at the rest-house at an altitude of 15,500 feet and then on the summit at an altitude of 19,000 feet. After obtaining observations at Mollendo, Dr. Compton returned to the United States via Mexico, where observations were also made in the neighborhood of Mexico City. From Mexico City he proceeded directly to Churchill, Canada, taking the last boat of the season to Chesterfield Inlet, the International Polar Year station, where observations were obtained. Observations were also made during the 95 per cent eclipse at a point 100 miles north of the Arctic Circle and 350 miles from the magnetic pole. He expected to return to Churchill about September 10 to 12.

Dr. *Robert A. Millikan,* of the California Institute of Technology, left Pasadena on September 1, 1932, for an expedition to conduct measurements on the cosmic rays as close to the north magnetic pole as transportation facilities permit. The Royal Canadian Air Corps will furnish planes. It is expected that Dr. Millikan will continue his work through the United States as far as Texas.

26. *Magnetic observations during eclipse August 31, 1932*—H. W. Fisk, C. C. Ennis, H. D. Harradon, and R. H. Mansfield of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, assisted by Prof. Thos. C. Poulter of Iowa Wesleyan College, made special magnetic observations during the eclipse of August 31, 1932, under the direction of Mr. Fisk. Messrs. Fisk and Mansfield located their station at Five Elms Farm some five miles west of St. Johnsbury, Vermont. Messrs. Harradon and Ennis were at West Bethel, Maine, and Professor Poulter was at East Wakefield, New Hampshire.

27. *Errata*—In foot-note 4 on page 237 of the September 1931 number of the JOURNAL the date should be 1929 instead of 1930. The title of Table 2 on page 9 of the March 1932 number of the JOURNAL should read "*u-measure*" instead of "u_1*-measure.*"

28. *Personalia*—Geheimrat Prof. Dr. *H. Hergesell,* member of the International Commission for the Polar Year, 1932-1933, retired on April 1, 1932, from the directorship of the Lindenberg Aeronautical Observatory, which he has held since May 1, 1914.

Dr. *L. Steiner* retired from the directorship of the Royal Hungarian Institute for Meteorology and Terrestrial Magnetism in Budapest on July 1, 1932, after 40 years of service. Vice-Director George Marczell has been provisionally entrusted with the direction of the Institute.

G. W. Littlehales, hydrographic engineer in the U. S. Hydrographic Office, retired on August 1, 1932, after completing 47 years' service in the United States Navy Department. Mr. Littlehales has always shown much interest in the subject of terrestrial magnetism and was one of the contributing editors of this JOURNAL for the period 1899-1909.

Dr. *H. H. Kimball* retired June 30, 1932, from the staff of the United States Weather Bureau. He has been in charge of the solar-radiation investigations of that Bureau since 1908 and has made noteworthy contributions to that subject.

STATISTICAL METHODS FOR RESEARCH ON DIURNAL VARIATIONS

By J. Bartels

Abstract—It is explained that research on the variability of the diurnal variations is necessary, because the usual method of discussing the average variations alone leads one to overlook characteristic features of the phenomenon. The use of harmonic dials for this purpose is described, and the formulae for numerical and graphical work are given. The use of the two-dimensional standard deviation and of the probable ellipse for estimating the accuracy of average diurnal variations is explained. The procedure is applied to the diurnal variation of declination on quiet days at Huancayo observatory in southern summer, and the results are discussed. The variability is surprisingly large and affects both amplitudes and phases of the sine-waves. Some days with particularly large and small amplitudes are picked out. Preliminary results of similar calculations for Watheroo Observatory are summarized, among others the remarkable dial for the 24-hourly wave in horizontal intensity, which indicates that the focus of the diurnal atmospheric current-system passes on some days north, on other days south of Watheroo. Some remarks on future work are added.

The following paper has a two-fold connection with the work of Dr. L. A. Bauer, to whose memory this issue of the Journal is dedicated: The first is the use of material of an observatory (Huancayo, Peru), which was founded under his direction by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and whose unusual records of the diurnal magnetic variation may be regarded as the most valuable addition to terrestrial-magnetic observations within the last years. The second connection lies in the attempt—so characteristic of Bauer's theoretical papers—to mitigate the unavoidable vagaries of a geophysical phenomenon by using the largest possible amount of material, to master it by means of suitable statistical methods, and, thus, to make the natural variability serve for revealing the physical nature of the phenomenon.

1. *The problem*—A complete description of a geophysical phenomenon must give an account not only of its average value or appearance, but also of its variability, in order to form a basis for a theoretical explanation. Take, for instance, the daily readings, at noon, of the air-temperature on summer-days at a given station; the mere average is no sufficient abstract of the observations, if it is not supplemented by information on the frequency and intensity of hot and cold spells. Adequate expressions and modes of description for the variability have long been derived in general statistics. They are, however, mostly applicable in such cases only in which each observation can be expressed by one quantity (frequency-curves) or two quantities (theory of correlation), while these methods are not readily transferred to research on periodical variations, for instance, those with the period of a solar day.

Consider the solar diurnal variation (called S) of a magnetic element at a given station, say, declination D at Huancayo, Peru. The D-variometer records S for each day, from midnight to midnight, as a continuous curve. The first simplifying step consists in deriving the usual hourly means. We shall regard, in this paper, the diurnal variation S for each quiet day (only quiet days will be considered) as given by the twenty-five hourly means from 0^h to 1^h up to 0^h to 1^h of the next day; this allows for possible non-cyclic changes. N days would yield a set of N combinations of 25 values. It is proposed to develop statistical

methods for dealing with such a set, which is equivalent to a "Kollektiv" or "population" in German or English papers on statistics. The choice of methods will have to allow for the strong interdependence of the 25 values.

The usual way of preparing this material for discussion is to derive average diurnal curves S for a number of days by computing the 25 averages for the hourly intervals. Such groups of days are formed, for instance, according to season, sunspot-number, and magnetic activity, in order to study the systematic influence of these phenomena on S. Though this procedure has yielded valuable results, it can in no way be claimed to disclose the full variability of S. In the example of the air-temperature, for example, it would correspond to computing averages for different seasons, for high or low pressure, etc., while the temperature may vary considerably from quite different causes which have perhaps been overlooked. The full variability of the temperature is better represented by the frequency-distribution, which gives, for suitably chosen steps, the relative number, or percentage, of days on which the noon-temperature lies in the interval between, say, 10° and 11°C, etc. This frequency-distribution is easily calculated from the original observations, without regard to any real or supposed cause. Our problem is to find a suitable analogon to it which might represent the full variability of S, as distinguished from the more or less regular changes of S with season, sunspots, or magnetic activity. That part of the variability of S, which can as yet not be accounted for by the influence of season, sunspots, or other well-known causes, might be called irregular or fortuitous. Since it will be found to be of the same order of magnitude as the regular changes, it deserves to be studied in detail.

2. *The range as a characteristic of the diurnal variation*—An obvious possibility for simplification exists in the further condensation of the observational material. Three characteristics of S, every one expressed by a single number, have been offered: The *range*, that is, the difference between the highest and lowest value for the day; the *non-cyclic variation*, that is, the increase or decrease of the value at the end of the day as compared with the initial value (twenty-fifth minus first hourly mean); and the *daily mean*, that is, the average of all values for the day. S. Chapman and J. M. Stagg[1], have used these three characteristics, especially the range, in an extensive study of S on very quiet days, with international magnetic character-figures 0.0 or 0.1, at various observatories. They have obtained the first information about the irregular variability of S; in the physical interpretation of their valuable statistical results, they are led to a distinction between world-wide and regional causes which affect S.

The advantage of characterizing S by the range alone is the reduction of the numerical work and, consequently, the possibility to work up and survey the conditions on a great number of days. Even in physical respect, the simple procedure could apparently be justified to a certain extent, because it was found that the curve representing the average diurnal variation S on days with large ranges differs from that for days with small ranges only in scale, but not in shape. In other words: S, the aggregate of the 25 values for each hour h, may be considered as the superposition of a daily mean, a linear non-cyclic varia-

[1]Proc. R. Soc. London, A, **123**, 27-53 (1929); **130**, 668-697 (1931).

tion and the diurnal variation proper, $s(h)$, expressed in deviations from the mean, and corrected for the non-cyclic variation. If this, purely mathematical, decomposition is done for each day, and if $s_+(h)$ and $s_-(h)$ are the average curves for days with large and small ranges, then $s_+(h)/s_-(h)$ is found to be a constant ratio, not changing with the day-time h. This would of course involve, that in the usual harmonic analysis of $s(h)$,

(1) $s(h)=\Sigma(a_j \cos jh \cdot 15°+b_j \sin jh \cdot 15°)=\Sigma c_j \sin(jh \cdot 15°+\alpha_j),(j=1, 2, \ldots)$

the corresponding harmonic coefficients a_j, b_j, c_j, of $s_+(h)$ and $s_-(h)$ stand in the same ratio, while the phases α_j are the same, or the maxima occur at the same times, $h_{j\,\max.}=(90°-\alpha_j)/j\ 15°$.

This inference is, however, not supported by our own results; in fact, the variability of S at a number of stations reveals quite distinct correlations between changes of amplitudes and phases. This was first brought out for the Sitka Observatory, Alaska, where the 24-hourly sine-wave in horizontal intensity on quiet days attains its maximum about 1 or 2 hours *earlier*, when the amplitude is large, than when it is small[7]. In the present paper, the method of investigation will be fully described, and some results obtained for the two observatories of the Carnegie Institution of Washington at Huancayo (Peru) and Watheroo (Western Australia), will be discussed along similar lines as in the former paper.

3. *The variability of the diurnal variation represented by harmonic dials*—Intervals of 24 hours coinciding with the Greenwich civil day, and guaranteed as magnetically quiet by the international magnetic character-figures 0.0 or 0.1, are selected and subjected to harmonic analysis, with correction for non-cyclic variation. *Local* mean midnight is then chosen as origin of time h in formula (1). For each day and magnetic element, S is then represented by the daily mean, the non-cyclic variation, and before all, by a set of harmonic constants a_1, b_1; a_2, b_2; a_3, b_3; a_4, b_4; higher harmonics are generally insignificant. For each period of $(24/j)$ hours length, the usual harmonic dial[2] is plotted with a_j and b_j as rectangular coordinates, a_j upward, b_j toward the right. For reference, the dials for the 24-hourly wave $(j=1)$ in declination D, horizontal intensity H, and vertical intensity Z will be called D_1, H_1, and Z_1, for the 12-hourly wave D_2, H_2, and Z_2, etc. In the dial D_1, for instance, the 24-hourly sine-wave in declination for each day is represented by a dot, which is to be considered as the end-point of a clock-hand, which points towards the time of maximum $(h_{j\,\max.})$ as read from the scale of the dial, and indicates, by its length, the amplitude c_1.

N days are represented on each dial as a "*cloud*" of N points, and the variability of S is now transformed into the geometrical properties of these clouds which can be readily investigated. General statistical theorems suggest the following procedure: Suppose a cloud of N points in a plane with the rectangular coordinates X_ν, Y_ν $(\nu=1, 2, \ldots, N)$. The coordinates of the center C are $X_0=\Sigma X_\nu/N$, $Y_0=\Sigma Y_\nu/N$. In deviations from the center C, the coordinates may be called $x_\nu=X_\nu-X_0$, $y_\nu=Y_\nu-Y_0$. We put

(2) $$\sigma_x^2=\Sigma x_\nu^2/N,\ \sigma_y^2=\Sigma y_\nu^2/N,\ r\sigma_x\sigma_y=\Sigma x_\nu y_\nu/N$$

[7] J. Bartels, Pub. Nation. Res. Council, Trans. Amer. Geophysic. Union, 12th annual meeting, p. 130 (1931).

where r is the usual correlation-coefficient between X_ν, Y_ν, or, also, between x_ν, y_ν. The general Gaussian frequency distribution (or "normal correlation-surface") which fits the cloud best, as judged by the method of least-squares, is then expressed by the probability $w(x, y)\,dxdy$, that a point is situated in the rectangle $(x, x+dx, y, y+dy)$, namely[3]

$$w(x, y) = w_0 e^{-Q(x,y)/2} \tag{3}$$

with

$$w_0 = 1/2\pi\sigma_x\sigma_y\sqrt{1-r^2} \tag{4}$$

$$Q(x, y) = \frac{1}{1-r^2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} - \frac{2rxy}{\sigma_x\sigma_y}\right) \tag{5}$$

The lines of equal frequency are ellipses $Q(x,y) = \text{constant}$ with the center C; the major and minor axes have all the same ratio. The major axis is inclined toward the x-axis by the angle θ, where

$$\tan 2\theta = 2r\sigma_x\sigma_y/(\sigma_x^2 - \sigma_y^2) \tag{6}$$

θ must be chosen between 0° and 90° for $r>0$, and between 90° and 180° for $r<0$. For $r=0$, θ is 0° or 90°, according to whether σ_x or σ_y is the greater; for $r=0$ and $\sigma_x=\sigma_y$, the ellipses degenerate into circles.

If the coordinate-system x,y is turned by the angle θ into the new system ξ, η, which coincides with the major and minor axes of the ellipses (Fig. 1), Q is transformed into

$$Q(\xi,\eta) = \xi^2/\sigma_\xi^2 + \eta^2/\sigma_\eta^2 \tag{7}$$

where

$$\sigma_\xi^2 + \sigma_\eta^2 = \sigma_x^2 + \sigma_y^2 = M^2 \tag{8}$$

say, and

$$\sigma_\xi^2\sigma_\eta^2 = \sigma_x^2\sigma_y^2\,(1-r^2) \tag{9}$$

By means of (8) and (9), the standard deviation σ_ξ, σ_η along the axes can be calculated from the standard deviations σ_x, σ_y along the original axes and from the correlation-coefficient r. From (2) and (8) it follows that

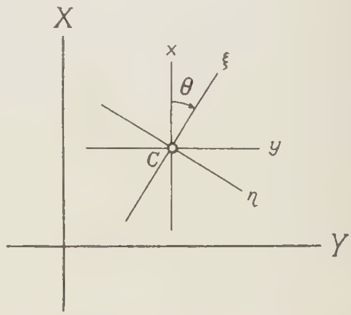


Fig. 1—Coordinate-systems used in the geometrical description of clouds of points

$$M^2 = \Sigma(x_\nu^2 + y_\nu^2)/N \tag{10}$$

is the average square distance of each point from the center C. M is useful if it is desired to measure the dispersion of the cloud by a single number, disregarding ellipticity, and may be called the *two-dimensional standard deviation.*

[3]Because of the differences in notation and certain generalizations, the main formulae are given above in a form suitable for numerical application. For proofs and relations to other statistical methods see K. Pearson, Phil. Mag. London, series 6, 2, 559-572 (1901), and Tables for statisticians and biometricians, Table XXIV, Cambridge 1914; G. U. Yule, Introduction to the theory of statistics, Chapter XVI, 8th ed., London 1927; E. Czuber, Theorie der Beobachtungsfehler, p. 343 f., Leipzig 1891; R. von Mises, Wahrscheinlichkeitsrechnung, pp. 56-61, Leipzig 1931.

In the ideal case of a perfect Gaussian distribution, the total probability that a point falls outside the ellipse Q=constant is found simply as $e^{-Q/2}$. The *probable ellipse* which contains $N/2$ points inside, $N/2$ outside, belongs therefore to $e^{-Q/2}=1/2$, or $Q=\log \text{nat } 4$. The major and minor axes P_1 and P_2 of the probable ellipse are therefore, by (7), obtained from σ_ξ and σ_η by multiplication with $\sqrt{\log \text{nat } 4}=1.17741$. Writing the solution of (8) and (9) in a suitable form, we obtain thus

$$(11) \qquad P_1, P_2=0.83256\sqrt{(\sigma_x^2+\sigma_y^2)\pm\sqrt{(\sigma_x^2-\sigma_y^2)^2+4r^2\sigma_x^2\sigma_y^2}}$$

where the + sign gives the major, the − sign the minor axis of the probable ellipse.

We note further that in general

$$(12) \qquad \sqrt{P_1^2+P_2^2}=1.1774\ M$$

In the case of circular symmetry ($\sigma_x=\sigma_y$, $r=0$), $P_1=P_2=0.833\ M$.

The actual calculation runs thus: σ_x^2, σ_y^2, $r\sigma_x\sigma_y$ are computed from (2), M from (8), θ from (6), P_1, P_2 from (11). These values can *always* be calculated, because the formulae do not presuppose that the cloud is Gaussian, but give only the constants of a Gaussian distribution which fits the given cloud best. If a diagram should reveal the cloud as obviously non-Gaussian—for instance with points clustered around two different centers—the constants P_1, P_2, etc., will not be *wrong*, though they will have little meaning. In our cases, however, the cloud will be fairly Gaussian or "normal" in appearance; an easy, though only partial, test is to draw the probable ellipse and to count the number of points inside and outside, which must be nearly equal. More severe arithmetical tests of normality are in general not applicable, because they require very much material. If, therefore, we treat a distribution as normal, it is advisable to strain the conclusions not too much and to use the properties of the normal distribution with that "grain of salt" which is necessary in all applications of the theory of probability.

From what has been said about the definition of the probable ellipse, it is easy to find the probability that a point falls outside an ellipse with the axes κP_1, κP_2 as $(1/2)^{\kappa^2}$, for instance, 1/16 for $\kappa=2$, 1/512 for $\kappa=3$, 1/66000 for $\kappa=4$, 1/33million for $\kappa=5$, $1/7\times10^{10}$ for $\kappa=6$. For all practical purposes, no point is therefore to be expected outside the ellipse with the six-fold probable axes.

4. *Application to the accuracy of average harmonic amplitudes and phases*—The formulae given in §3 will be used later in the discussion of the physical significance of clouds of points on harmonic dials. There is, however, another field of application, namely, the estimate of the reliability of harmonic constants obtained from the average of a limited number of periods. If we again transfer this problem, by means of the harmonic dial, into a similar problem for clouds of points, we can state it in the following way: Suppose the number of points in the cloud is very great, $N=nk$, say, and the points are numbered 1, 2, 3, . . ., nk. The full cloud can then be conceived as the superposition of k partial clouds of n successive points each. The centers of the partial clouds may be C_1, C_2, . . . C_k. We suppose now, that the situations of successive points are completely *independent* of each other, or, in

other words, that each of the partial clouds has been selected from the full cloud at random, say, by drawing n lots in a lottery with N tickets[4]. None of the partial centers $C_1, C_2, \ldots C_k$ will, in general, coincide with the center C of the full cloud. Fundamental theorems of statistics assert that, for large numbers n and k, the law for the geometrical distribution of the partial centers $C_1, \ldots C_k$ is obtained from the distribution of the $N=nk$ single points by simple reduction of scale in the ratio $1/\sqrt{n}$; in particular, if M, θ, P_1, P_2 have been obtained from all N single points, as in §3, the probability for the situation of the partial centers $C_1, \ldots C_k$ relative to C is governed by ellipses around C, which have the characteristic parameters $m=M/\sqrt{n}$, θ, $p_1=P_1/\sqrt{n}$, $p_2=P_2/\sqrt{n}$. The remarks at the end of §3 hold, with these reduced parameters, also, and will usually form the practical essence of the whole calculation.

For the actual application the following consideration is necessary: Observation yields only a partial cloud, with a center, say, C_1, from n observations, and it is desired to estimate how far C_1 can be regarded as representative for C, the center of a cloud of very many observations, $N=nk$ in number. If n is not too small—say, greater than 50—we can safely derive the elements of the distribution, M, θ, P_1, and P_2, from the *partial* cloud alone, and can say that the probable situation of C relative to C_1 is governed by the elements $m=M/\sqrt{n}$, θ, $p_1=P_1/\sqrt{n}$, and $p_2=P_2/\sqrt{n}$ (just as the situation of C_1 relative to C).

This complete inversion of the relations between C and any one of the partial centers is not quite exact, and the elements are accurate only to the order of $1/n$ of their values. The difference between the "*real*" distribution, relative to C, and the "*apparent*" distribution, relative to any partial center C_1, has sometimes been over-emphasized; we follow, however, Yule and von Mises in neglecting it by stipulating that no practical application of the theory of errors can be trusted, in which $1/n$ cannot be neglected against unity, or, in other words, in which the omission of a single observation [$(n$-$1)$ instead of n] would alter the results seriously.

A frequent problem is the question whether the distance between two centers C' and C'' is to be considered as physically significant. If both clouds have circular symmetry, and the standard deviations of the single points are M', M'', the probable radii for C' and C'', as derived from n' and n'' observations are $p'=0.833\ M'/\sqrt{n'}$, $p''=0.833\ M''/\sqrt{n''}$. If the distance between C' and C'' is $\kappa\sqrt{p'^2+p''^2}$, the probability that C' and C'' appears separated by pure chance (and not for a physical reason) is $(1/2)^{\kappa^2}$, for which numerical values are given at the end of §3. If C'' is the origin of the coordinate-system, then $M''=0$, and $(1/2)^{\kappa^2}$ becomes, in the case of an harmonic dial, the expression for the *probability that C' represents a physically significant amplitude.* In this manner the probable-error circle was first used by the author in the derivation of atmospheric tides from pressure observations, a method which has recently been described in this JOURNAL[5].

[4]In the terminology of R. von Mises, we assume the cloud to be a "Kollectiv", the conception of which is discussed at length in his book cited above.

[5]Terr. Mag., **37**, p. 22f (1932); see also M. A. Tuve, Pub. Nation. Res. Council, Trans. Amer. Geophys. Union, 13th annual meeting, Washington, p. 166 (1932).

The assumption that the successive points are *independent* is essential for the deduction of the $(1/\sqrt{n})$-law of propagation of errors, and for the inference from the shape of the partial cloud to that of the full cloud. The choice of a partial cloud is, however, in practice often imposed by circumstances unfavorable for independence. For instance, successive days may have to be analyzed; then it is suggested by the results of Chapman and Stagg that a day with large harmonic amplitudes is likely to be followed by another one with large amplitudes. Such *after-effects* always make the application of the law for the propagation of errors illusory, and lower the reliability of the average. In fact, after-effects act just as a diminution of the number N of available data. Suppose, for instance, that always four successive points lie close together; the center of all points will then be about the same as that of the first, fifth, ninth, . . ., points, that is, of $N/4$ points only. A good test of independence is to take the average square of the distances of successive points; in the ideal case of independence it ought to be $2M^2$, while any after-effect would lower this value. If the effect of interdependence is overlooked, the accuracy of the average will be overrated—a source of frequent errors in geophysics.

On the other hand, strong after-effects can be utilized in order to shorten the computational labor. In the example just mentioned, when four successive points are always clustered together, neither the accuracy of the average, nor the knowledge of the distribution would be impaired, if only one of every such "quartet" were used in the calculations. In the case of the diurnal variations in terrestrial magnetism and meteorology, the strong interdependence of successive hourly means can be utilized, if, in studies on variability at least, only every alternate hourly mean is used. This reduction of the material to one-half of its original amount has been used by the author in all work of this kind, with considerable saving of computing time and no relevant loss in accuracy. The correctness of this procedure has recently been confirmed by S. Chapman[6], in the computation of the lunar diurnal variation of atmospheric temperature at Batavia.

5. *The variability of the diurnal variation of declination at Huancayo in summer*—It is to be expected, and confirmed by the observations, that about the time of the solstices the systematic seasonal change of the diurnal variation S is small; these times of the year were therefore selected as favorable for the discussion of the irregular variability of S, and, in particular, the summer-solstice, when S is usually more pronounced. In order to provide for any trace of a seasonal change of S, the following five intervals were formed: October 14 to November 10, November 11 to December 8, December 9 to January 4, January 5 to February 1, February 2 to 29; the length of each interval is 28 days except for the middle interval, which is centered at the solstice and which is 27 days long. These intervals were used for the southern summer 1925-26, 1926-27, etc., to 1929-30; this period can be characterized as near a sunspot-maximum, because the average relative sunspot-number for the months November and December 1925 to 1929, and January and February 1926 to 1930, is 71.

The dates with international character-figures 0.0 or 0.1 were selected, omitting a few days on which the D-record in Huancayo failed for in-

[6]Proc. R. Soc., London, A, 137, p. 19 (1932).

strumental reasons. The number of these quiet days in each interval is 26, 36, 25, 23, and 19, respectively. Harmonic analyses of the D-variations in the 24 hours between successive Greenwich midnights were computed from the twelve hourly means for 0^h-1^h, 2^h-3^h, etc., Greenwich time, that is 19^h-20^h (preceding day), 21^h-22^h, . . ., 18^h-19^h standard time 75th meridian West of Greenwich; the coefficients for the periods of 24, 12, 8, and 6 hours were corrected for non-cyclic variation and for the use of hourly means, so that they represent instantaneous values[7]. All phases were afterwards expressed in mean local time of Huancayo. It was found that the average harmonic coefficients for each of the five intervals do not differ appreciably, except for the first interval. This was therefore excluded, and only the $n=103$ days falling between November 11 and February 29 were combined in harmonic dials. In order to eliminate even the last residual of the seasonal variation, the four "clouds" for the four intervals were drawn for each interval separately, and then superposed (by mere shift without turning) with coinciding averages (or cloud-centers). The result is Figure 2, in which also the probable ellipses are drawn; the curious shape of the dials is chosen for economy. The ends of the axes are marked by short lines on the probable ellipse. Numerical data are contained in Table 1. A change of $1'$ in D is equivalent to a magnetic force of 8.64γ at right-angles to the magnetic meridian at Huancayo. The direction of the major axis of the ellipse (that is, the angle θ) is indicated in Table 1 by the hour which a parallel line through the origin would mark on the dial.

Table 1

Harmonic analysis of diurnal variation of easterly declination at Huancayo, Peru, and its variability derived from 103 days with international character-figures 0.0 or 0.1 in southern summer during a sunspot-maximum during intervals November 11 to February 29, 1925-26 to 1929-30

Term, j	1	2	3	4
Period, hours	24	12	8	6
	Average diurnal variation			
Amplitude c_j (γ)	11.1	10.0	4.7	1.5
Phase α_j	260°.3	102°.6	283°	180°
Local time first maximum	$12^h.6$	$11^h.6$	$3^h.7$	$4^h.5$
	Variability			
Standard deviation $M(\gamma)$	6.4	5.6	3.5	2.3
Axis probable ellipse P_1 (γ)	6.43	4.92	3.13	2.10
Axis probable ellipse P_2 (γ)	3.95	4.37	2.58	1.69
Direction major axis	$12^h.3$	$10^h.2$	$2^h.5$	$4^h.8$
Ratio P_1/P_2 (ellipticity)	1.63	1.13	1.21	1.24
Ratio c/M	1.7	1.8	1.3	0.7

[7]For the reduction-factors, based on bi-hourly *differences*, see Gerlands Beitr. Geophysik **28**, 1-10 (1930).

6. *Discussion*—Considering the nearness of Huancayo to the magnetic equator, far from polar disturbances, and, further, the extreme magnetic quietness for which these 103 days have been selected, it is surprising to note the great variability as exhibited in the scattering on Figure 2. The system of formulae used seems to fit this scattering; the probable ellipses represent the distribution fairly well. On counting out the number of dots inside and outside the ellipse, they are found to differ only by a few, so that the assumption of a Gaussian distribution seems to be adequate. Furthermore, we find agreement with the calculations at the end of §3, according to which, in 103 cases, no dot should be expected outside the ellipse which is produced by three-fold magnification of the probable ellipse.

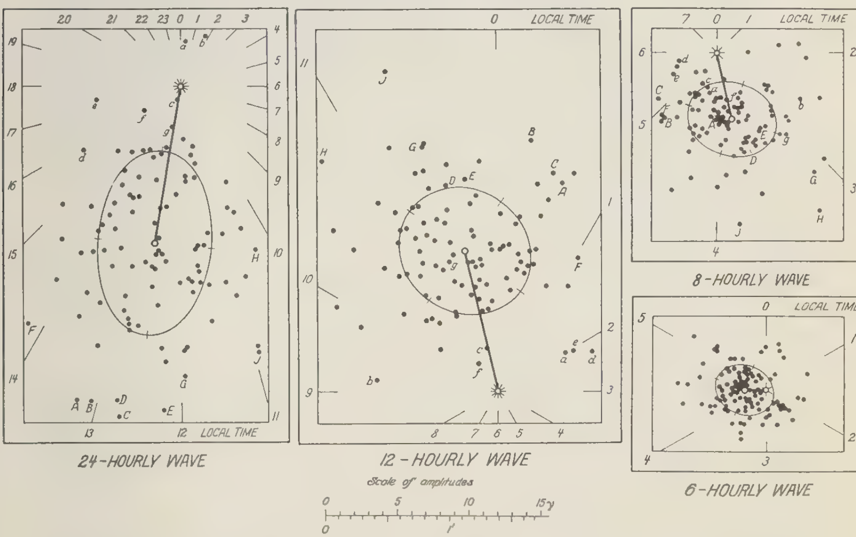


FIG. 2—Harmonic dials for 24-hourly, 12-hourly, 8-hourly, and 6-hourly sine-waves in diurnal variations of easterly declination at Huancayo Observatory on 103 single very quiet days in southern summer—each dot marks one day; the length of the vector from the center gives the amplitude, and its direction, as read from the dial, gives the local mean time of the first maximum of the sine-wave; the letters *a*, *b*, . . ., *g*, *A*, *B*, . . ., *J* mark particular days whose dates are given in the text; the average vector is also drawn, and the probable ellipse

The 24-hourly cloud has the most marked ellipticity. The direction of the major axis indicates that changes in the 24-hourly wave affect the amplitude more than the phase. On single days the amplitude c_1 may vary as much as 100 per cent of the normal. The other clouds have negligible ellipticities. The absolute scattering M diminishes with increasing frequency j, but relative to the average amplitude c_j, the fourth wave (6-hourly) scatters most. This is also indicated by the ratios c/M in the last line of Table 1.

Each of the 103 days is represented by a dot on each of the four

diagrams. The strong interrelations between the diagrams are indicated in the following way: In the 24-hourly dial, the following days were selected as having the smallest amplitudes: (*a*) Dec. 21, 1925; (*b*) Jan. 27, 1930; (*c*, *d*, *e*) Feb. 21 to 23, 1927; (*f*) Jan. 14, 1928; (*g*) Nov. 21, 1928. The following days were selected as having the largest amplitudes: (*A*) Jan. 27, 1929; (*B*) Dec. 19, 1929; (*C*) Feb. 3, 1929; (*D*) Nov. 28, 1928; (*E*) Feb. 11, 1928; (*F*) Nov. 18, 1929; and (*G*) Jan. 3, 1927. Besides, two days were selected from the 12-hourly dial, namely, (*H*) Feb. 24, 1928 and (*J*) Jan. 9, 1927. These days are marked by the same letters on the dials for the waves of the 24-, 12-, and 8-hour periods, the six-hourly dial being omitted as insignificant. The following conclusions can then be drawn from an inspection of the first three dials: Days with small or large amplitudes in one wave can be expected to have correspondingly small or large amplitudes in the other waves. A good example for the interdependence of the ranges on successive days, as found by Chapman and Stagg, is furnished by the three successive days (*c*), (*d*), and (*e*) with small amplitudes. That the interrelation between the dials is not restricted to amplitudes, is shown by the day (*F*), on which the maxima of all three waves occur more than one hour later than normal, and the day (*H*), on which they occur earlier than normal. Such outstanding anomalies of the diurnal variation can of course readily be recognized in the original records, or in the hourly means.

7. *Preliminary results obtained from Watheroo data*—For the Watheroo Observatory, Western Australia, computations were made similar to those described in §5 for Huancayo, but more extensive in so far as two groups (170 days for sunspot-maximum, and 165 days for sunspot-minimum) were available, and all three magnetic elements (declination D, horizontal intensity H, and vertical intensity Z) could be worked up for the southern summer. Pending final publication and discussion, some results may be indicated. In Watheroo, the average diurnal variation in H is small; yet it is surprising to note a pronounced ellipticity in the 24-hourly cloud for H (ratio of the axes $P_1/P_2=1.70$ for sunspot-maximum years and 1.46 for sunspot-minimum years). This indicates that the small average amplitude is produced by the combination of single days with larger amplitudes but opposite phases. The physical

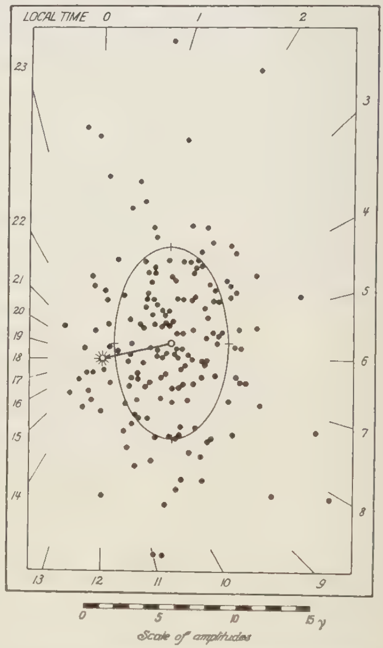


FIG. 3—Harmonic dial for the 24-hourly sine-waves in diurnal variations of horizontal intensity at Watheroo Observatory on 171 single, very quiet days in southern summer

interpretation is a corresponding shift in the focus of the atmospheric diurnal current-system, which, on the average, passes nearly overhead at Watheroo, but, considered on single days, passes sometimes north, sometimes south of the observatory.

Figure 3 gives the 24-hourly cloud for H for 171 very quiet days taken from the sunspot-maximum years 1919 and 1925 to 1929. While the average 24-hourly wave has an amplitude $c_1=4.5\gamma$ only, and its maximum occurs about 5^h, the scattering is at right-angles to this average vector. Now, at equatorial stations, the maximum of the 24-hourly wave in H occurs at noon, while at polar stations it occurs at midnight. For those days on the dial which are represented by dots in the upper half, towards 0^h (midnight), the focus of the diurnal atmospheric current-system must therefore have passed between Watheroo and the equator, while on the days with maximum towards 12^h (noon), the focus must have passed between Watheroo and the south pole.

The idea of the diurnal variations in the three elements as an entity is supported, from these Watheroo data, by strong relations between the diurnal variations in D and Z, comprising both amplitudes and phases. This connection will later be illustrated by a generalized harmonic dial[2]. On the whole, the results seem to strengthen the hypothesis that the variability of the diurnal variation is mainly the result of regional changes in the diurnal atmospheric current-system, which affect not only its intensity, but also its form, and which, finally, can be interpreted either as the result of more or less "patchy" ionization, or of regional wind-systems in the high atmosphere. The explanation of this variability of S will be a good test for all theories of the diurnal magnetic variations.

8. *Some remarks on future work*—As soon as hourly means of horizontal intensity at Huancayo will be available for several years, a similar analysis of this material will be of special interest because of the enormous diurnal amplitudes (24-hourly amplitude $c_1=53\gamma$ for the average of all days 1929-30[8]) The simple form of the diurnal curve of H indicates the desirability of using, instead of harmonic analysis, a parabola fitting the variation in the daytime. A few other points will be to search for relations between the diurnal variations recorded, on the same day, at Watheroo and Huancayo, and, possibly, other observatories, and, further, to compute the lunar variation for days with small and with large amplitudes of the solar variation, provided a sufficient accuracy can be attained.

In the course of the systematic computation of the solar and lunar variations at Watheroo during the years 1919-30, now in progress, it has already been found (confirming earlier work) that the *average* solar diurnal-variation S varies but little with activity. Up to international character-figures 1.1, there is hardly a systematic change of S; in fact, the average S for days with international character-figures between 0.8 and 1.1 differs from the average S for days with character-figures 0.0 to 0.2 much less, than the *single* days with character-figures 0.0 and 0.1 differ from their own average. This will be useful when attacking the question as to how anomalies of S persist through several days, for which only a few examples have been shown in §6, namely, succes-

[8]H. F. Johnston and A. G. McNish, Cong. Internat. Elect., Paris 1932., Sect. 11, Comm. No. 2-C-3, 12 p . (1932)

sive days (*c*), (*d*), and (*e*) with small amplitudes and the days formerly published[9]. While several very quiet days occur rather rarely in succession, more material bearing on the persistence will be available if days with somewhat higher character-figures may be included in the succession.

Finally, such summaries of the variability of the diurnal variation as given in Table 1 will always, apart from their physical significance, form the basic clue for all questions pertaining to the reliability of average diurnal variations, as shown in §4; similar tables for other observatories are therefore desirable. Because of the small difference in the lengths of solar and lunar days, the standard deviations M, as derived from solar diurnal-variations, can at once be used for lunar diurnal-waves.

[9]J. Bartels and W. J. Rooney, Terr. Mag., **37**, 53-55 (1932).

Forstliche Hochschule,
Eberswalde, Germany

SEASONAL MAGNETIC VARIATIONS AT APIA

By P. W. Glover

§1—This paper is an account of a preliminary investigation into seasonal changes in the terrestrial magnetic elements as recorded at the Apia Observatory, Western Samoa[1].

§2—Four months—January, April, July, and October representative of the seasons summer, autumn, winter, and spring, respectively—were selected for study, and the means of the diurnal variations for "all days" for each of the quantities horizontal force, declination, and vertical force over the five-year period 1916-20 inclusive, were formed from the data given in the Apia Observatory publication "Summary of Magnetic Observations 1912-1920." It was considered that this selection of months over the period named should be sufficient to show the trend of any seasonal changes and to indicate in a general way, the results to be expected from a more detailed investigation.

§3—The following points are to be noted in regard to the diagrams and to what follows. In the case of $\triangle H$ and $\triangle D$, a negative sign is to be interpreted as indicating an hourly value of the appropriate element smaller than the mean value for the day. Since Z is negative in Samoa, a negative sign for $\triangle Z$ indicates that the hourly value is numerically greater but algebraically smaller than the mean for the day. Declination is East, and therefore positive. In all cases, the diurnal variations are means over complete hours; but in the diagrams, they are referred to by the numbers of the Greenwich hours beginning the periods. For example, a value given for 3^h is to be understood as the mean value over the hour 3^h to 4^h G.M.T.

§4—The diurnal variations of D and H are plotted in Figure 1, and of Z in Figure 2. The curves for H do not show any pronounced seasonal variation as deduced from migration of the times of maxima and minima. In the cases of D and Z, however, the maxima and minima do show pronounced migrations through the seasons. Table 1 which follows summarizes these points. Variations in the ranges of these quantities are treated in section 7.

Table 1

Element	Month	Maximum	Minimum	Maximum	Minimum
		h *h*	*h* *h*	*h* *h*	*h* *h*
H	January.....	23—24	8—9	.. ..	.. ..
	April........	23—24	8—9	.. ..	.. ..
	July........	22—23	8—9	.. ..	.. ..
	October.....	23—24	6—7	.. ..	.. ..
D	January.....	2—3	13—14	15—16	19—20
	April........	3—4	11—12	17—18	21—22
	July........	3—4	11—12	18—19	23—24
	October.....	1—2	12—13	16—17	20—21
Z	January.....	4—5	16—17	20—21	23—24
	April........	3—4	17—18	.. ..	.. ..
	July........	2—3	19—20	.. ..	.. ..
	October.....	4—5	15—16	.. ..	.. ..

[1]Since it came under control of the government of New Zealand the Apia Observatory has had the cooperative scientific as well as some financial assistance of the Carnegie Institution of Washington initiated by the interest of Bauer, as director of the Department of Terrestrial Magnetism, who always appreciated and emphasized the strategic value to terrestrial magnetism and electricity of this uniquely located Observatory.—*Ed.*

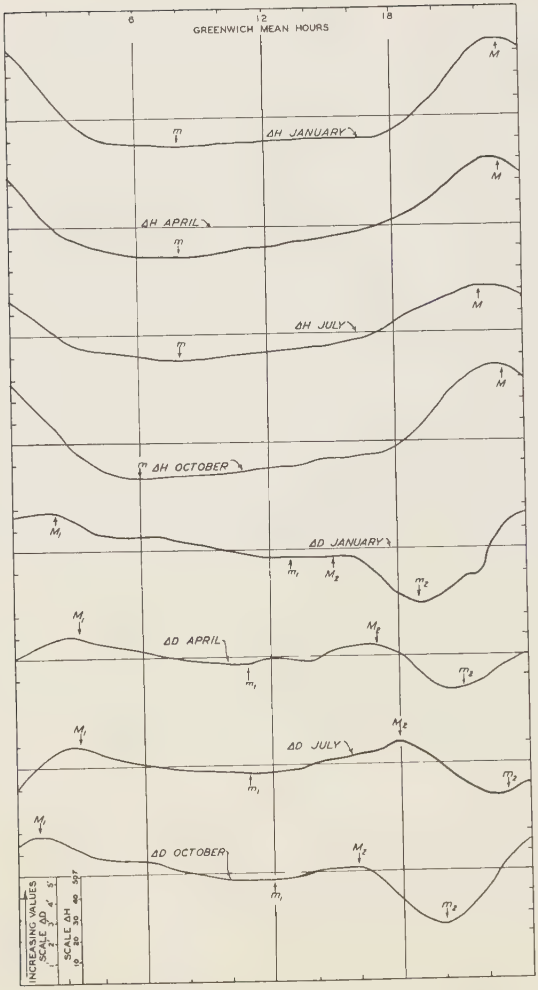


FIG. 1—Diurnal variations of D and H, Apia Observatory

January may be considered a summer month; April, an autumnal one, July a winter month, and October a spring month. Thus for D, both of the maxima and also the second minimum occur later in autumn and winter than in spring and summer, while the first minimum occurs earlier in autumn and winter than in spring and summer; but for Z second maxima and minima were found only for January (summer), though the hump in the October curve suggests the tendency for these to occur also in the spring at approximately the same times as in January.

§5—From the data for H and D the diurnal variations $\triangle X$ and

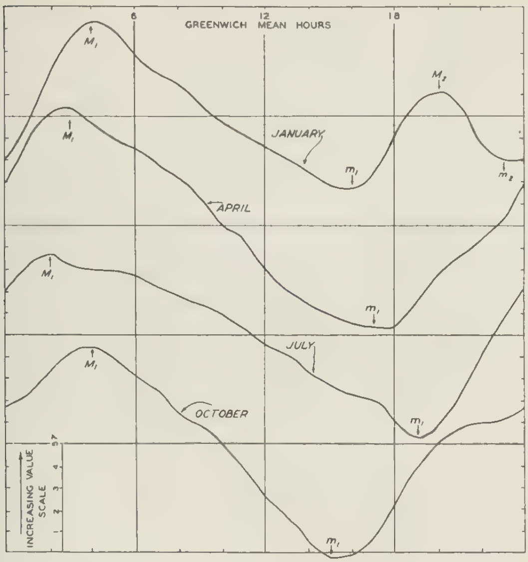


FIG. 2—Diurnal variation of Z, Apia Observatory

$\triangle Y$ of the northerly and easterly components of the horizontal force were computed for the purpose of drawing the vector-diagrams for the selected months. These diagrams appear, all drawn to the same scale, in Figure 3. A great difference is here seen between the diagrams for the autumn-winter and the spring-summer months. In these diagrams considerable difference is noted in the times of the vector crossing the magnetic meridian. The Greenwich Mean Times of these are given in Table 2.

TABLE 2

Month	G.M.T. of vector crossing the magnetic meridian from			
	E to W	W to E	E to W	W to E
	h	h	h	h
January	10.5	....	....	22.5
April	8.2	13.8	18.7	00.3
July	8.5	14.3	20.2	01.3
October	9.1	14.3	16.9	23.1

It will be noticed that the re-entrant portions of the diagrams for October and January are very small compared with those for April and July. In particular, the re-entrant portion of the diagram for July is so large that it crosses over the earlier portion for some hours. The diagrams for October and January are very open in character, while those for April and July are very much closed up.

§6 -The disturbing force $\triangle F$ was calculated for each hour from the values of $\triangle X$, $\triangle Y$, and $\triangle Z$. The mean values and ranges for the individual months are given below in Table 3, the unit being one gamma, and are also shown graphically in Figure 4.

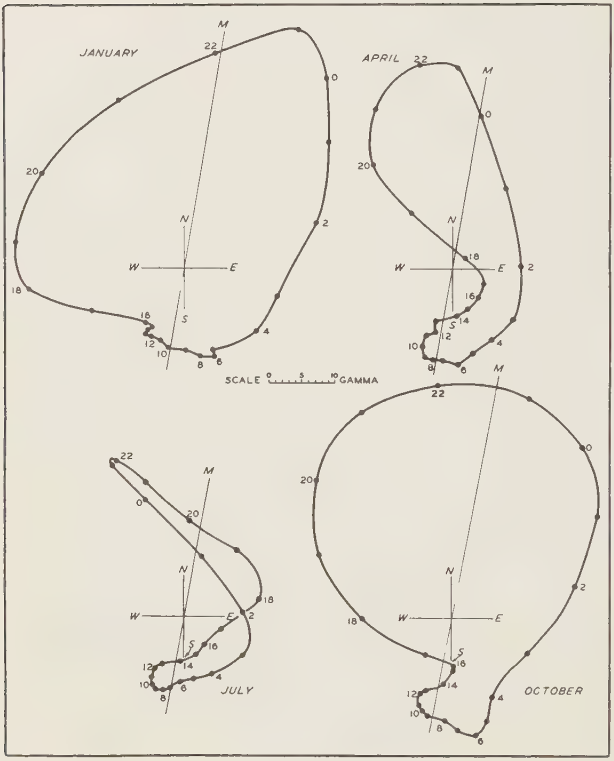


Fig. 3—XY vector-diagrams of diurnal variation, Apia Observatory

Table 3

Element	Month			
	January	April	July	October
	γ	γ	γ	γ
Mean value of ΔF...	19	14	12	19
Range of ΔF.......	29	25	19	27

It is seen that in the spring and summer months, both the mean value and range of $\triangle F$ are in excess of the corresponding values for the winter months.

§7—Figure 4 shows the ranges of the diurnal variations of the magnetic elements, and also the Sun's declination, and the mean of the monthly means of the Wolfer provisional sunspot-numbers for the five years considered. It is immediately obvious that there exist seasonal variations in the ranges of the various diurnal variations, and that in general, they seem to vary roughly as the Sun's south declination,

being greatest when the south declination is at its maximum, and least when the south declination is at its minimum. The curve of the Wolfer numbers exhibits a pronounced irregularity in April, due to an ab-

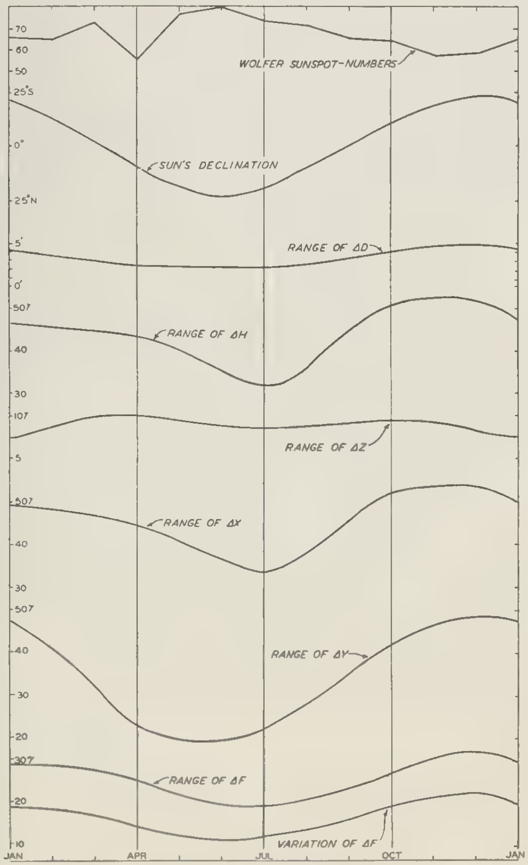


FIG. 4—Comparison of sunspot-numbers and Sun's declination with annual ranges of ΔD, ΔH, ΔZ, ΔX, ΔY, ΔF, and variations of ΔF at Apia Observatory

normally low value in that month of 1920. If this is disregarded, it would also appear that some relation may exist between the sunspot-numbers and the ranges. An attempt was made to establish a linear relation between $\triangle F$ and S, the Wolfer number, of the type

$$\triangle F = a + bS$$

Neglecting April on account of the abnormality in S, the relation $\triangle F = 90 - 1.1S$ was obtained, which gave for January, July, and October, $\triangle F_c = 18\gamma$, 10γ, and 20γ respectively as compared with 19γ, 12γ, and

19γ from Table 3. The result however is unconvincing, and it is doubtful whether any high degree of correlation really exists. In any case, the quantity of data used is much too small to permit of any great accuracy in the evaluation of the constants a and b.

§8—From the foregoing discussion, it is evident that the magnetic elements at Apia do exhibit very definite seasonal variations. These may be briefly summarized as follows:

(*a*) The times of maxima and minima of D and Z show marked migrations through the seasons. This effect is not clearly shown in H.

(*b*) The horizontal plane vector-diagrams exhibit well marked changes of character with the seasons. The times of the vector crossing the magnetic meridian also show seasonal fluctuations.

(*c*) The ranges of the variations of the magnetic elements, show for the most part, definite seasonal variations.

A more thorough and detailed investigation for every month over a much longer period is contemplated in the hope of deriving quantitative results and of determining the causes of the variations. From the present work, it would appear that the cause may possibly be connected with the variation of the Sun's declination and perhaps also with activity on the Sun's surface.

§9—The following papers have been consulted during the investigation:

G. Angenheister, Sonnentätigkeit, Strahlung, und Erdmagnetismus im Verlauf der Sonnenrotation. Göttingen, Nachr. Ges. Wiss., 11-12 (1920).

G. Angenheister, Periodicity of activity in terrestrial magnetism and the rotation of the Sun. Terr. Mag. **27,** 57-79 (1922).

C. J. Westland, The effect of the sunspot-cycle on the magnetic diurnal-variation at Apia. Terr. Mag., **36,** 6-8 (1931).

G. Angenheister, Der jährliche Gang der erdmagnetishen Aktivität. Terr. Mag., **25,** 53-56 (1920).

Apia Observatory—Summary of magnetic observations 1912-1920 Wellington (1927).

Apia Observatory
Apia, Western Samoa

EINIGE ERGÄNZUNGEN DER KLASSISCHEN DEVIATIONS-THEORIE[1]

Von H. Meldau

Die klassische Deviationstheorie, wie sie z.B. im "Admiralty Manual for the Deviations of the Compass" enthalten ist, nimmt zunächst an, dass nur "fester" und "flüchtiger" Magnetismus im Schiffe vorhanden sind. Unter der weiteren Voraussetzung, dass die Komponenten des vom "flüchtigen" Magnetismus am Kompassort erzeugten Feldes lineare Funktionen der Komponenten des erdmagnetischen Feldes seien, gelten für den "Kompassort" bei aufrecht auf ebenem Kiel liegendem Schiffe die bekannten, zuerst von S. D. Poisson aufgestellten Gleichungen[2]

$$\begin{aligned} X' &= X + aX + bY + cZ + P \\ Y' &= Y + dX + eY + fZ + Q \end{aligned} \tag{1}$$

Aus diesen Gleichungen lässt sich die Ablenkung eines im Kompassort aufgestellten Kompasses berechnen, wenn man noch voraussetzt: (1) dass die Kompassnadeln als unendlich klein im Vergleich zur Entfernung der nächstgelegenen Eisenmassen oder Magnetpole angesehen werden können; (2) dass keinerlei Nadelinduktion im Spiele ist, d.h., dass die Kompassnadeln nicht ihrerseits eine merkliche Induktion in den nächstgelegenen Eisenmassen hervorrufen. Das Erfülltsein dieser Forderungen seitens der Eisenmassen des Schiffes selbst ist bei vernünftig gewähltem Kompassort gewährleistet, es ist aber dann in Frage gestellt, wenn Magnete und Weicheisenmassen zur Kompensation der vom Schiffe erzeugten Ablenkung am Kompasshause angebracht werden. Das zeigte sich zuerst um das Jahr 1860 bei der Kompensation der Kompasse des berühmten "Great Eastern." Im Gefolge der Kompensation traten sechstel- und achtelkreisige Deviationen auf, die von A. Smith und F. J. Evans als Folgen der gegenüber der Entfernung der Kompensationsmittel nicht zu vernachlässigenden Nadellängen erkannt wurden. Gleichzeitig zeigten die Genannten (Phil. Trans. R. Soc., 1861), dass die Störungen durch geeignete Anordnung der Kompassnadeln beseitigt werden können, z.B. bei einer Zweinadelrose dadurch, dass man den Polen der Nadeln einen Winkelabstand gleich 30 Grad von der Nordsüdlinie gibt.[3]

Rücksicht auf Nadelinduktion war dann der Grundgedanke, von dem W. Thomson (Lord Kelvin) bei der Konstruktion seiner Rose ausging. Von der extremen Forderung, die Thomson in dem Satz aussprach (London, Proc., **22**, 1874): "The Chinese compass or needle unloaded with compass-card is undoubtedly the compass of the future" musste zur Erzielung der nötigen Ruhe auf bewegtem Schiff ein gutes Stück zurückgegangen werden. Immerhin ist für die Thomsonrose und alle ihr seitdem nachgebildeten Trockenrosen die Nadelinduktion für die praktischen Zwecke der Schiffahrt so klein, dass sie vernachlässigt

[1]In his letter of transmittal, the author stated that he had selected as his contribution a report on some investigations on which he was engaged during a visit from Dr. Bauer who at the time evinced considerable interest in the subject.—*Ed.*

[2]Hier und im folgenden ist die international angenommene, aus dem Admiralty Manual bekannte Bezeichnung angewandt. Die positive X-Achse ist nach vorn, die Y-Achse nach Steuerbord, die Z-Achse nach unten gerichtet. X, Y sind die Komponenten des erdmagnetischen, P, Q die des "festen" schiffsmagnetischen, X', Y' die des Gesamtfeldes.

[3]In der zitierten Abhandlung ist meistens von den Enden der Nadel die Rede. Die wichtige Unterscheidung von "Polen" und "Enden" ist in der Folgezeit vielfach nicht genügend beachtet worden. Vergl. Ann. Hydrogr., **32**, 161-169 (1904).

werden darf.[4] Ebenso macht eine hinreichend einwandfreie Nadelanordnung bei diesen Rosen keine Schwierigkeit.

Anders ist die Sachlage bei Schwimmkompassen, auf die man heute ihrer grösseren Ruhe wegen auf vielen Fahrzeugen angewiesen ist. Hier kommt man ohne verhältnismässig lange und kräftige Nadeln nicht aus, sodass die klassische Deviationstheorie einige Erweiterungen, insbesondere hinsichtlich der Wirkung der Nadelinduktion in den zur Kompensation angebrachten Weicheisenmassen erfahren muss.

Als solche Weicheisenmassen kommen in der Regel die in der Mittschiffsebene stehende *Flindersstange* und die querab vom Kompass angebrachten $\mathfrak{D}$-*Korrektoren* in Betracht.

Die unmittelbare Anschauung zeigt, dass Nadelinduktion in der *Flindersstange* im wesentlichen eine Quadrantaldeviation D sin $2\zeta'$ mit positivem Wert des D, dagegen Nadelinduktion in den $\mathfrak{D}$-*Korrektoren* im wesentlichen eine Quadrantaldeviation mit negativem D erzeugt.

Es verlohnt nicht, die durch Nadelinduktion in der Flindersstange entstehende Deviation näher zu untersuchen: da sie das vom Schiffe herrührende positive D noch erhöhen würde, so hat man allen Grund, Nadelinduktion in der Flindersstange zu vermeiden, indem man die Stange weit genug vom Kompass entfernt anbringt.

Die kompensierende Wirkung von $\mathfrak{D}$-Korrektoren, die in erster Linie durch erdmagnetische Induktion wirken, wird durch stattfindende Nadelinduktion noch verstärkt. Man kann durch Verkleinerung der Eisenmassen unter gleichzeitigem Näherrücken erreichen, dass die erdmagnetische Wirkung ganz vernachlässigt werden darf, sodass man *rein durch Nadelinduktion wirkende* $\mathfrak{D}$-*Korrektoren* erhält.[5] Solche sollen hier betrachtet werden.

Vorher seien die aus den Gleichungen (1) folgenden Werte der Deviation δ und der "Feldstärke nach magn. Nord" zusammengestellt. Dabei dürfen für die hier vorliegenden Zwecke die vom Kurse unabhängigen Felder P, cZ, Q, und fZ als verschwindend angenommen werden. Ferner seien normale Verhältnisse, also $b = 0$, $d = 0$, vorausgesetzt. Dadurch wird die Schreib- und Sprechweise sehr vereinfacht, ohne dass die Allgemeinheit der Untersuchung wesentlich beeinträchtigt wird.

Wird mit H die Horizontalfeldstärke des Erdmagnetismus, mit H' die gesamte, auf die Rose wirkende Feldstärke, ferner mit ζ der vom (magnetischen) Meridian gezählte "magnetische Kurs," mit ζ' der "Kompasskurs" bezeichnet, so sind die Komponenten des Erd- und des Schifffeldes

$$(2) \qquad \text{nach vorn:} \quad H' \cos \zeta' = (1 + a)\, H \cos \zeta$$

$$(3) \qquad \text{nach Stb.:} \quad -H' \sin \zeta' = -\,(1 + e)\, H \sin \zeta$$

Es ist $\delta = \zeta - \zeta'$. Setzt man $[1 + (a + e)/2] = \lambda$; $(a - e)/2\lambda = \mathfrak{D}$, so sind die Komponenten

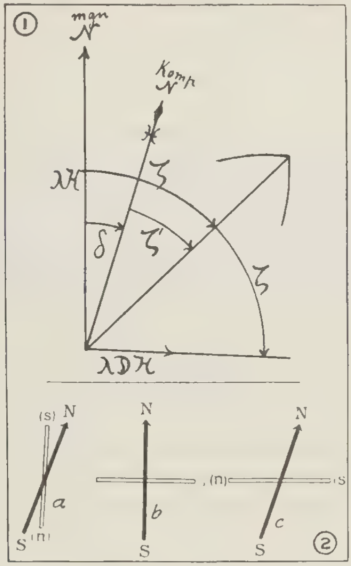
$$(4) \qquad \text{nach magn. Nord:} \quad H' \cos \delta = \lambda H + \lambda\mathfrak{D}\, H \cos 2\zeta$$

$$(5) \qquad \text{nach magn. Ost:} \quad H' \sin \delta = \lambda\mathfrak{D}\, H \sin 2\zeta$$

d.h. zum "meridianfesten" Feld λH kommt ein Feld $\lambda\mathfrak{D} H$ im Winkel 2ζ gegen den Meridian, also ein Feld, das sich doppelt so schnell dreht wie das Schiff.

[4] Vergl. Ann. Hydrogr., **33**, 171-180 (1905).

[5] An Stelle von zwei Weicheisenmassen, die querschiffs in gleicher Entfernung von der Rosenmitte angebracht sind, kann auch ein kleiner querschiffs unter oder über der Rose befestigter Weicheisenstab treten.



FIGS. 1 UND 2

Die Rose ist im Gleichgewicht, wenn die Summe der auf sie wirkenden Drehmomente verschwindet. Bezeichnet M das magnetische Moment der Rose, so lautet daher die Gleichgewichtsbedingung[6] (s. Fig. 1)

$$- M \lambda H \sin \delta + M \lambda \mathfrak{D} H \sin (\zeta + \zeta') = 0$$

Es ist also

$$\text{(6)} \qquad \sin \delta = \mathfrak{D} \sin (\zeta + \zeta')$$

oder

$$\text{(7)} \qquad \sin \delta = \mathfrak{D} \sin (2\zeta - \delta); \text{ oder } \sin \delta = \mathfrak{D} \sin (2\,\zeta' + \delta)$$

woraus die Formeln folgen

$$\text{(8)} \qquad \operatorname{tang} \delta = \frac{\mathfrak{D} \sin 2\zeta}{1 + \mathfrak{D} \cos 2\zeta} \qquad \text{oder } \operatorname{tang} \delta = \frac{\mathfrak{D} \sin 2\zeta'}{1 - \mathfrak{D} \cos 2\zeta'}$$

Für die Praxis ist meistens erwünscht, δ als Funktion des *Kompasskurses* ζ' zu haben. Bis zu Gliedern von der Ordnung $\mathfrak{D}^3$ ist

$$\text{(9)} \qquad \delta = D \sin 2\zeta' + H \sin 4\zeta' + N \sin 6\zeta'$$

wo $\qquad D = \mathfrak{D}, \qquad H = (1/2)\,\mathfrak{D}^2, \qquad N = (1/3)\,\mathfrak{D}^3.$

Eine durch erdmagnetische Induktion erzeugte Quadrantaldeviation $D \sin 2\zeta'$ ist demnach in erster Linie mit einer Oktantaldeviation als Begleiterscheinung verknüpft. Mit der Kompensation des D verschwindet auch diese Oktantaldeviation. Durch geeignete Nadelanordnung muss dafür gesorgt werden, dass nicht infolge der Kompensation eine neue Oktantaldeviation eingeführt wird.

[6]Diese Form ist hier gewählt, weil die Betrachtung von Drehmomenten im folgenden nötig ist.

Die "Feldstärke nach magn. N." ist durch Gleichung (4) gegeben. Für die Hauptstriche folgt aus (4)

$$\begin{aligned} (10) \qquad H_n' &= H_s' = (1 + a)\, H \\ H_o' &= H_w' = (1 + e)\, H \end{aligned}$$

Es sei daran erinnert, dass die Konstanten a und e fast stets negative Werte haben, sodass $\lambda < 1$. Dabei ist e dem absoluten Betrage nach grösser als a, sodass $\mathfrak{D}$ positiv. Dieses Wertverhältnis sei im folgenden als vorliegend vorausgesetzt.

Das von einem $\mathfrak{D}$-Korrektor, der rein durch Nadelinduktion wirkt, auf die Rose ausgeübte Drehmoment $\triangle_k$ ist lediglich von der Stellung des Korrektors gegen das Nadelsystem der Rose abhängig. Wird diese Stellung durch einen Winkel v definiert, so kann $\triangle_k$ als periodische Funktion durch eine Reihe von der Gestalt

$$\begin{aligned} \triangle_k = c_0 &+ c_1 \sin v + c_2 \sin 2v + c_3 \sin 3v + \ldots \\ &+ c_1' \cos v + c_2' \cos 2v + c_3' \cos 3v + \ldots \end{aligned}$$

dargestellt werden. Nimmt man für v den Winkel zwischen der Längsschiffssymmetrieebene des Korrektors und der magnetischen Achse des Rosensystems, so reduziert sich die Reihe aus Symmetriegründen auf

$$(11) \qquad \triangle_k = c_2 \sin 2\, v + c_4 \sin 4\, v + c_6 \sin 6\, v + \ldots$$

Die Koeffizienten $c_2, c_4, c_6, \ldots$ hängen von der Gestalt der Weicheisenmassen, ihrer Entfernung von der Rosenmitte, der magnetischen Beschaffenheit des Eisens, ferner vom magnetischen Moment des Nadelsystems und von der Länge und der Anordnung der Rosennadeln ab. Daher lässt sich die Frage nach der einwandfreien Wirkung eines $\mathfrak{D}$-Korrektors nicht in Bezug auf den Korrektor für sich, sondern nur in Bezug auf die Zusammenstellung des Korrektors mit einem bestimmten Nadelsystem beantworten.

Die Kompensation ist dann und nur dann exakt, wenn der Korrektor das vom Schiff auf die Rose in ihrer Meridianstellung ausgeübte Drehmoment

$$\triangle = M \lambda \mathfrak{D} H \sin 2\, \zeta$$

für alle Werte von ζ aufhebt. Da in der Meridianstellung der Rose $v = \zeta$ zu setzen ist, muss also

$$c_2 \sin 2\zeta + c_4 \sin 4\zeta + c_6 \sin 6\zeta + \ldots = - M \lambda \mathfrak{D} H \sin 2\, \zeta$$

sein, d.h. die Koeffizienten $c_4\; c_6, \ldots$ müssen verschwinden, was durch passende Nadelanordnung der Kompassrose zu erreichen ist, und dem Koeffizienten c_2 ist durch geeignete Entfernung der Weicheisenmassen von der Rosenmitte der Wert

$$(12) \qquad c_2 = - M \lambda \mathfrak{D} H$$

zu erteilen.

Untersuchung des Nadelsystems—Die *Untersuchung*, ob für die gewählte Zusammenstellung: "Nadelsystem und Korrektor" der Koeffizient c_4 verschwindet, kann am Lande in eisenfreier Umgebung am besten mittels eines *Mehrkorrektorversuches* ausgeführt werden. Man ordnet zu dem Zwecke einen zweiten, dem ersten gleichen Korrektor rechtwinklig zum ersten an. Auf die im Meridian festgehalten gedachte Rose wirken dann die Drehmomente

$$\triangle_1 = + c_2 \sin 2\zeta + c_4 \sin 4\zeta + c_6 \sin 6\zeta + \ldots$$
$$\triangle_2 = - c_2 \sin 2\zeta + c_4 \sin 4\zeta - c_6 \sin 6\zeta +$$

Das Gesamtdrehmoment hat demnach bis auf Glieder höherer Ordnung den Wert

$$\triangle_1 + \triangle_2 = 2\, c_4 \sin 4\zeta$$

Wenn es von Null verschieden ist, so treibt es die Rose aus dem Meridian heraus. Bleibt hingegen nach Anbringung der kreuzweise zueinander gestellten Korrektorpaare die Rose bei Drehung der Vorrichtung um die Rosenmitte in Ruhe, so verschwindet der Koeffizient c_4 im Drehmoment.

Eine entsprechende Probe für das Verschwinden von c_6 würde sich durch Korrektoren erreichen lassen, die im Winkel von 60 Grad zueinander gestellt sind.

Der hier beschriebene *Mehrkorrektorversuch* bietet auch in anderen Fällen die schärfste und bequemste Probe für richtige Nadelanordnung. Man kann z.B. sechs Pole, und zwar abwechselnd N- und S-Pole, in den Ecken eines regelmässigen Sechsecks anordnen und diese Vorrichtung um die Rosenmitte drehen. Dann heben sich bei gleicher Stärke der Pole alle halbkreisigen Ablenkungen gegenseitig auf, während etwaige auf falscher Nadelanordnung beruhende sechstelkreisige Ablenkungen versechsfacht in die Erscheinung treten.

Stellt man auf Grund dieser Probe ein Nadelsystem her, das als asextantal zu bezeichnen ist, so erweist sich dieses unter der Wirkung von $\mathfrak{T}$-Korrektoren, die *rein durch erdmagnetische* Induktion[7] wirken, ebenfalls als frei von oktantalen Störungen $H \sin 4\zeta'$.

Für $\mathfrak{D}$-Korrektoren, die *rein durch Nadelinduktion* wirken, ist das nicht ganz der Fall, hier ergab sich in allen von mir untersuchten Fällen bei exakt asextantaler Nadelanordnung ein Koeffizient H mit negativem Vorzeichen[8] — von grösserem oder geringerem Betrage je nach der Gestalt der benutzten Weicheisenmassen und dem magnetischen Moment des Nadelsystems[9]. Der Betrag ist übrigens nicht derartig, dass daraus praktische Schwierigkeiten entstehen. Aufschluss ist im gegebenen Falle ohne weiteres durch den Mehrkorrektorversuch zu erlangen.

Eichung des Korrektors—Um den *Korrektor zu eichen*, d.h. für verschiedene Entfernungen seiner Weicheisenmassen von der Rosenmitte die zugehörigen Werte des c_2 zu bestimmen, beobachtet man in eisenfreier Umgebung am Lande, wo die Horizontalfeldstärke des Erdmagnetismus H_0 sei, die vom Korrektor erzeugten Ablenkungen δ_0. Es ist bei einwandfreier Wirkung des Korrektors auf die Rose

$$M\, H_0 \sin \delta_0 = c_2 \sin 2\zeta'$$

also

$$c_2 = M\, H_0 \sin \delta_0 \;{\scriptstyle (\zeta' = 45°)} \tag{13}$$

[7]Dieser Ausdruck ist nicht ganz korrekt. Tatsächlich befinden sich solche Korrektoren an Bord in dem vereinigten Feld des Erd- und des Schiffsmagnetismus. Treffender ist der Ausdruck "durch Feldinduktion wirkende $\mathfrak{D}$-Korrektoren."

[8]Ann. Hydrogr., **47**, 272 (1919).

[9]Wenn A. Smith (Phil. Trans. R. Soc., 1861) auf Grund theoretischer Ableitung zu dem Schluss kommt ". . . . that the same construction of the compass which prevents a sextantal error arising from the length of the needle when a permanent magnet affects it, prevents the like error when the *needle acts on and is reacted on by soft iron,*" so stimmt das nicht ganz. In der Tat ist der Fall der Nadelinduktion theoretisch schwer genügend exakt zu erfassen.

Die Kompensation eines an Bord vorhandenen $\mathfrak{D}$ an einem Orte mit der Horizontalintensität H erfordert deshalb nach (12) dass

$$(14) \qquad -\lambda\,\mathfrak{D}\,H = H_0 \sin\delta_{0\,(\zeta'=45^\circ)}$$

ist. Tabuliert man für die verschiedenen Entfernungen der Weicheisenmassen von der Rosenmitte die Werte von $H_0 \sin\delta_{0\,(\zeta'=45^\circ)} : \lambda\,\mathfrak{D}$, so kann man der Tabelle für jeden Wert des Horizontalintensität H die zur Kompensation erforderliche Korrektoreinstellung entnehmen.

Wie vorauszusehen war, ist die Kompensation nicht breitenbeständig.

Eine ähnliche Untersuchung für $\mathfrak{D}$-Korrektoren, die teilweise durch erdmagnetische Induktion und teilweise durch Nadelinduktion wirken, führt zu dem Ergebnis, dass ein solcher Korrektor an Bord ein

$$(15) \qquad \mathfrak{D} = \frac{H_0}{\lambda H}\left[-\sin\delta_{0\,(\zeta'=45^\circ)} + \mathfrak{D}'\cos\delta_{0\,(\zeta'=45^\circ)}\right] - \mathfrak{D}'$$

kompensiert. Hierin bedeutet $\mathfrak{D}'$ den auf erdmagnetischer Induktion beruhenden Betrag, während H_0 und $\delta_{0\,(\zeta'=45^\circ)}$ dieselbe Bedeutung haben wie oben.

$\mathfrak{D}'$ kann für Kugelkorrektoren und für Weicheisenkörper von ellipsoidischer Gestalt durch Rechnung gefunden werden. Sonst bleibt nur die experimentelle Bestimmung mit zwei Rosen von gleichem Bau, aber verschiedenem magnetischem Moment übrig.

Einfluss eines durch Nadelinduktion wirkenden D-Korrektors auf das Einstellungsvermögen der Kompassrose—Wird eine Kompassrose vom magnetischen Moment M, die sich in einem *homogenen Magnetfeld* von der Stärke H' befindet, um den Winkel α aus ihrer stabilen Gleichgewichtslage herausgedreht, so erfährt sie ein Moment

$$(16) \qquad \triangle = -M\,H' \sin\alpha$$

wo das Minuszeichen andeuten soll, dass zu einem positiven Wert von α ein negatives $\triangle$ d.h. ein rückdrehendes Moment gehört.

Für das "Einstellungsvermögen" (die Stabilität des Gleichgewichts) ist daher das Produkt $-MH'$ massgebend, das als "Richtmoment" R bezeichnet werden soll

$$(17) \qquad R = -M\,H'$$

Der so erklärte Begriff des Richtmoments ist für einen durch Nadelinduktion wirkenden $\mathfrak{D}$-Korrektor nicht mehr ausreichend. Von einem homogenen, durch den Korrektor am Rosenort erzeugten Feld kann keine Rede sein; ausserdem ist das Einstellungsvermögen bei Vorhandensein von Nadelinduktion nicht nur durch die in der Ruhelage vorhandenen magnetischen Kräfte bedingt, sondern zum Teil auch durch Kräfte, die bei der Bewegung der Rose um die Ruhelage herum erst geweckt werden. Das sei durch die schematische Figur 2 erläutert. Der Korrektor bestehe aus einem querschiffs unter dem Nadelsystem befestigten Weicheisenstab. Auf O- und W-Kurs, auf denen dieser Stab zu den Rosennadeln parallel liegt, induzieren diese in ihm ungleichnamige Pole, die offensichtlich das Einstellungsvermögen erhöhen (Fig. 2*a*). Auf *N*- und *S*-Kurs dagegen liegt der Stab quer zu den Nadeln (Fig. 2*b*), er wird also nicht induziert und ist scheinbar ohne jede Wirkung auf die Nadel. In der Tat ist vielfach die Meinung vertreten, man könne durch einen solchen oder ähnlichen durch Nadelinduktion

wirkenden Korrektor das *mittlere Einstellungsvermögen* erhöhen. Das ist jedoch irrig, denn bei jeder Drehung der Rose induziert diese im Stabe Pole, die das Bestreben haben, die eingeleitete Drehung zu vergrössern (Fig. 2c). Das Einstellungsvermögen wird deshalb auf N- und S-Kurs geschwächt.

Unter *Richtmoment im verallgemeinerten Sinne* sei der negativ genommene Differentialquotient $\frac{d\triangle}{d\alpha}$ an der Stelle $\alpha = \alpha_0$ verstanden, wo α_0 eine Gleichgewichtslage der Rose definiert:

$$(18) \qquad R = \left(-\frac{d\triangle}{d\alpha}\right)_{\alpha = \alpha_0}$$

Für den rein durch Nadelinduktion wirkenden $\mathfrak{D}$-Korrektor ergibt sich dann folgendes:

Auf die unter irgend einem Winkel α gegen den Meridian liegende Rose wirken ausser den vom Erd- und Schiffsmagnetismus herrührenden Drehmomenten

$$- M \lambda H \sin \alpha \quad \text{und} \quad + M \lambda \mathfrak{D} H \sin (2\zeta - \alpha)$$

das vom Korrektor herrührende Moment $c_2 \sin 2v$, wo v als Winkel zwischen Längsschiffslinie und Rosenachse gleich $(\zeta - \alpha)$ zu setzen ist, während für c_2 nach ausgeführter Kompensation der Wert $- M \lambda \mathfrak{D} H$ gilt. Es ist demnach

$$(19) \quad \triangle = - M\lambda H \sin \alpha + M\lambda\mathfrak{D} H [\sin (2\zeta - \alpha) - \sin (2\zeta - 2\alpha)]$$

Für $\alpha = 0$ wird $\triangle = 0$, d.h. der Meridian ist in der Tat Gleichgewichtslage. Der negativ genommene Differentialquotient

$$-\frac{d\triangle}{d\alpha} = + M\lambda H \cos \alpha + M\lambda\mathfrak{D}H [\cos (2\zeta - \alpha) - 2 \cos (2\zeta - 2\alpha)]$$

nimmt für diese Gleichgewichtslage den Wert an

$$(20) \qquad R = + M\lambda H [1 - \mathfrak{D} \cos 2\zeta]$$

Daraus ergibt sich für die Hauptstriche nach der Kompensation

$$R_n = R_s = M \lambda H [1 - \mathfrak{D}] = M (1 + e) H$$
$$R_o = R_w = M \lambda H [1 + \mathfrak{D}] = M (1 + a) H$$

während vor der Kompensation nach (10)

$$R_n = R_s = M (1 + a) H$$
$$R_o = R_w = M (1 + e) H$$

war. Demnach werden durch einen rein auf Grund von Nadelinduktion wirkenden $\mathfrak{D}$-Korrektor die Richtmomente auf den Kursen N und S gegen die auf den Kursen O und W ausgetauscht, sodass nach der Kompensation das (geringere) Richtmoment auf den Kursen N und S vorhanden ist, das vor der Kompensation auf den Kursen O und W herrschte und umgekehrt. Das Mittel der Richtmomente bliebt ungeändert.

Bei einem $\mathfrak{D}$-Korrektor, der rein durch erdmagnetische Induktion wirkt, sind bekanntlich die Richtmomente auf den Hauptstrichen nach ausgeführter Kompensation gleich. Das Mittel der Richtmomente kann durch einen solchen Korrektor erhöht werden.

Holbeinstrasse 13,
Bremen, Deutschland

NOTES

(See also pages 267, 277, and 290)

28. *Personalia* (continued)—Rev. *J. de Moidrey*, S.J., retired from the directorship of the magnetic section of the Zi-ka-wei Observatory in April 1932. Father de Moidrey has during the last fourteen years published a series of 39 Studies dealing with different aspects of terrestrial magnetism based chiefly on the work of the Observatory at Lu-kia-pang. Reverend *M. Burgaud*, S.J., succeeded Father de Moidrey as Director of the Magnetic Section of the Observatory.

Rev. *E. D. O'Connor*, S.J., has been appointed Rector of Stonyhurst College, and Rev. *J. P. Rowland*, S.J., has succeeded him as Director of the Stonyhurst College Observatory.

The following promotions to professorships have been made at the Massachusetts Institute of Technology: *Carl G. A. Rossby*, meteorology, and Dr. *Louis B. Slichter*, geology.

Dr. *Arthur E. Kennelly*, professor emeritus of electrical engineering at Harvard University, was elected on July 6, vice-president of the International Electrical Congress which met in Paris July 4 to 12, 1932.

J. A. Fleming, Acting Director of the Department of Terrestrial Magnetism and General Secretary of the American Geophysical Union, was elected an honorary and corresponding member of the State Russian Geographical Society in appreciation of his services in geophysics.

Stuart L. Seaton, who was in charge of the radio installations and investigations at the Huancayo Magnetic Observatory, has returned to the United States to resume his academic work, leaving Peru August 24, and is being replaced by *H. W. Wells*, who was formerly in charge of the radio investigations of the Malaysian Scientific Expedition in 1929 to 1930.

Dr. *L. W. Austin*, chief of the Laboratory for Special Radio Transmission Research at the United States Bureau of Standards and widely known for his studies of correlation between radio signal strength and geophysical phenomena, died at Washington, D. C., on June 26, 1932.

We have learned with regret of the recent death of Admiral *Umberto Cagni*, at the age of sixty-nine. He took part in two expeditions led by the Duke of the Abruzzi—the ascent of Mount St. Elias, 1897, and the Stella Polare Arctic Expedition of 1899-1900. On the latter expedition, he was second-in-command and in charge of the scientific observations.

Dr. *George K. Burgess*, director of the United States Bureau of Standards, died on July 2, 1932, at the age of fifty-eight years.

J. David Thompson, at one time a magnetic observer at the United States Coast and Geodetic Survey and for many years connected with the Library of Congress in various important capacities, died suddenly on August 14, 1932, at the home of his sister in Woodstock, N. Y., at the age of 69 years. Mr. Thompson was born in England and studied at the University of Cambridge and other English universities, where he left a brilliant record in mathematics and the physical sciences. He contributed reviews and bibliographical matter to some of the earlier numbers of this JOURNAL. He was also the author of the original draft of the system of classification now in use in the Library of the Department of Terrestrial Magnetism

THE DISTRIBUTION OF MASS IN MARINE COMPASSES

By W. J. Peters

This preliminary note was prepared for the memorial number of the Journal to show one phase of the investigation of compass-deviations caused by the rolling motion of ships, which seems suitable for this number because of its bearing on the making of magnetic observations of the highest precision at sea—a field which the Carnegie Institution of Washington in its Department of Terrestrial Magnetism under the direction of Bauer did so much to advance.

The distribution of mass in the designing of marine compasses with object of equalizing the moments of inertia about horizontal axes of the card was considered in the earliest investigations of the deviations of the compass.[1] It was found that "if two needles are placed parallel with their ends 30° on each side of the diameter and therefore 60° from each other, there will be no sextantal deviations. . . . These deviations will also disappear if two pairs of parallel needles are placed symmetrically on each of the diameter, one pair at 15° and the other at 45° from the diameter. . . . These results suppose the magnetism of the needles to be collected in one point at each extremity; but as the points in which the magnetism may with least error be considered as collected lie a short distance from the extremities, the consequence is . . . that the sextantal and octantal errors are slightly over-corrected; and the accuracy of the correction might doubtless be increased with little or no injury to the performance of the compass in other respects, by bringing the needles a little within the regulated distances of 30° and 60°."

The importance of the foregoing conclusions, which were obtained from a mathematical analysis of the effect of close proximity of iron, especially correctors, was emphasized by the fact that it was the magnetic effect of iron then newly introduced in ship-building that attracted the mathematical investigators. It was noted rather incidentally that the "wabbling motion"[2] was also diminished by these most advantageous distributions of the needles for reducing magnetic deviations of the higher terms. The existence of a *deviation*[3] in the mean position of the card during this so-called "wabbling motion" received probably no attention, and the importance of the distribution of mass has been somewhat overshadowed in seeking improvements in the distribution of the compass magnetic field.

Although some later writers have called attention to the desirability of equable distribution of moments, I have found only one[4] has pub-

[1] A. Smith and F. J. Evans, On the effect produced on the deviations of the compass by the length and arrangement of compass-needles. Phil. Trans. R. Soc. (1861). For magnetic effect see also C. Börgen, Zur Lehre von der Deviation des Kompasses. Aus d. Arch. Seewarte, **20**, No. 1 (1897), and Ueber die Anordnung der Nadeln einer Kompassrose zur Vermeidung der sextantalen und oktantalen Deviation. Aus d. Arch. Seewarte, **25**, No. 1 (1902); Ann. Hydrogr., **32**, 31-35 (1904).

[2] Loc. cit. See also footnote at end of paper by F. J. Evans, Reduction and discussion of the deviations of the compass observed on board of all the iron-built ships, and a selection of the wood-built steamships, in Her Majesty's Navy, and the iron steamship *Great Eastern*; being a report to the Hydrographer of the Admiralty, quoted from Phil. Trans. R. Soc. (1860) in: The magnetism of ships and the deviations of the compass, Washington, D. C., Bur. Navigation, Navy Dept., 7th paper, 18 (1867).

[3] The deviation produced by continued rolling, referred to in Terr. Mag., **34**, 100-101 (1929).

[4] T. A. Lyons, Electromagnetic phenomena and deviations of the compass, v. 2 (1903).

lished an investigation, and its full import is generally lost in subsequent specifications permitting somewhat uncertain departures from the rigid requirements of mechanics.

The principal moments of inertia, A and C, about the north-south and east-west axes, respectively, of a number of compasses used in the experiments of the Department of Terrestrial Magnetism[5] have been computed from the linear dimensions of the magnets and their distances from the center with uniform density assumed. The results although roughly approximate show values of $(A-C)$ which explain the changes in sign of the deviations found in these experiments. Experimental methods of greater precision than the method of computing from linear measurements with assumed even density are being tested before accepting final values of $(A-C)$ for these compasses. The differences $(A-C)$ are probably the results of attempting to follow specifications which refer to an imaginary circle, sometimes through the ends, sometimes through the poles of the magnets, and then permitting somewhat uncertain departures from the specified arcs of this circle.

In designing compasses for non-magnetic or only slightly magnetic vessels like the *Carnegie* and *Galilee*, or for a vessel of moderate deviations having a specially prepared non-magnetic region or for non-magnetic towing-devices which are now suggested, one is not hampered by considerations of the distribution of the magnetic field of the system of magnets. Therefore, the most rigid specifications practical for the proper distribution of mass can be followed in these cases, and it is even probable that rigid adherence as to mass-distribution would not conflict materially with the proper distribution of the magnetic field in all but very exceptional instances.

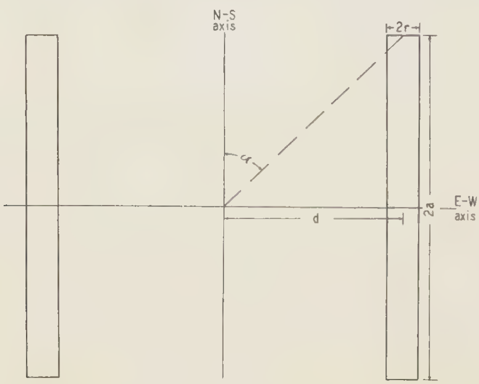


FIG. 1

The principal moments of inertia referred to axes through the centers of a system of bar-magnets, each of mass M, lengths $2a$, widths $2c$, thicknesses (heights) $2b$, at a distance d from the center or of a system of cylindrical magnets of radii r (see Fig. 1), are as follows:

[5]Terr. Mag., **34**, 98 and 112 (1929).

Axis	*Designation*	*Rectangular bars*	*Cylindrical bars*	
N—S	A	$\Sigma M\ (b^2 + c^2 + 3d^2)/3$	$\Sigma M\ (r^2+2d^2)/2$	(1)
E—W	C	$\Sigma M\ (a^2 + b^2)/3$	$\Sigma M\ (3r^2 + 4a^2)/12$	(2)
Vertical	B	$\Sigma M\ (a^2+c^2+3d^2)/3$	$\Sigma M\ (3r^2+4a^2+12d^2)/12$	(3)

Since for each magnet, I of the pairs, 1, 2, 3, etc., there must be another, II of same mass, shape, and distance from the center in order that the sums of the products of inertia disappear, we have rigid requirements

$$M_{\mathrm{I}} = M_{\mathrm{II}} = M \tag{4}$$

for each pair and, assuming cross-sections alike,

$$M_2 = (a_2/a_1)M_1,\ \ M_3 = (a_3/a_1)M_1 \tag{5}$$

for the system. The condition that the moments about every horizontal axis through the center shall be equal is for bar-magnets

$$(A—C) = \Sigma M\ (3d^2 - a^2 + c^2) = 0 \tag{6}$$

and for cylindrical magnets

$$(A—C) = \Sigma M\ (12d^2 - 4a^2 + 3r^2) = 0 \tag{7}$$

For a single pair of rectangular magnets, since $M_{\mathrm{I}} = M_{\mathrm{II}}$, the condition is expressed by

$$(3d^2 - a^2 + c^2) = 0$$

whence

$$d = \sqrt{(a^2 - c^2)/3} \tag{8}$$

Similarly for a pair of cylindrical magnets

$$d = \sqrt{a^2/3 - r^2/4} \tag{9}$$

In actual construction it may be found necessary, in order to exactly satisfy equations (4) and (5), that some minute change, a compromise, so to speak, on account of non-homogeneity of mass, will be necessary in the linear dimensions. Equations (8) and (9) considered with mass-equations show that d will not be affected if the minute change is made in b and that a smaller change in d will result from a change in r than would occur if the necessary change were made in a.

The value of d as given by equations (8) and (9) is exactly the same as is found in the investigations of the magnetic field referred to above if c or r is assumed to be zero. For then

$$d = a/\sqrt{3} \text{ and } \tan \alpha = 1/\sqrt{3} = \text{arc} \tan 30°$$

As a matter of fact, c or r may be very small, even small enough to neglect. The point, however, is that specifications giving lengths and distances are more tangible and easier to follow than those giving arcs of an imaginary circle.

For two pairs of magnets of same cross-section, equations (6) and (7) with the use of (5) reduce to

$$a_1^3 - (3d_1^2 + c^2)a_1 - a_2c^2 - 3a_2d_2^2 + a_2^3 = 0 \qquad \text{(rectangular)} \ (10)$$

$$a_1^3 - (3d_1^2 + 3r^2/4)a_1 - 3a_2r^2/4 - 3a_2d_2^2 + a_2^3 = 0 \quad \text{(cylindrical)} \ (11)$$

in which r or c and a_1 or a_2 are given. The three remaining quantities may

be taken to fulfill conditions as required. If a and d are taken so that the ends fall on a circle as required in the magnetic investigation, then

$$a_1^2 + d_1^2 = a_2^2 + d_2^2 \tag{12}$$

Further, if the ends of one pair, No. 2, are required to fall at 45° on this circle counted from the north-south axis, then

$$d_2 = a_2 \tag{13}$$

in which a_2 may be taken as given. Equations (12), (13), and (10) or (11) will then determine a_1 or d_1. These or derived equations would be used in designing a compass with the proposed objects in view, but the testing would require only the use of equations (6) or (7), since the lengths, distances, etc., could be measured from the finished card. Again, if r or c is assumed to be zero, equations (12), (13), and (10) or (11) will give $a_2 = 45°$ and $a_1 = 15°$ as required in the magnetic investigation. Equations (12) and (13) are not necessary for the condition of equable moments. If the conditions expressed by these two equations are not required, the condition for equable moments would hold by applying equations (6) or (7) to each pair of magnets separately.

The deviation caused by unequal moments depends on $(A—C)/B$ as a factor. Hence the deviation will also be reduced by increasing B to the maximum tolerance consistent with required compass-period and minimum friction.

It has been assumed that the principal axes of moments are the north-south and east-west axes, but compasses have been found for which this assumption does not hold. There are so many parts in the assembly of a marine compass-card, especially of the liquid type, that it requires the utmost care to keep the moments equal.

The card is leveled by placing the center of mass below the point of suspension and in the liquid type by also placing the center of buoyancy above the center of mass. With these arrangements the small magnetic couple should be so nearly balanced that additional weight would not be required. If, however, a counter-balancing weight is necessary, it should be noted that a larger mass near the axis will add a smaller moment of inertia to $(A—C)$ than a smaller mass further away, since the gravity-couple is mass times distance while the moment of inertia is mass times distance squared.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

IMPROVEMENTS IN MAGNETIC INSTRUMENTS AND METHODS ADOPTED BY THE COAST AND GEODETIC SURVEY*

By H. E. McComb

The present systematic survey of the United States by the United States Coast and Geodetic Survey was planned and organized by the late Dr. Louis A. Bauer as Chief of the Magnetic Division of the Survey, when, under his direction, five magnetic observatories were established and a comprehensive magnetic survey of the United States and outlying possessions was initiated. When he left the Survey in 1907 the observatories were operating on a routine basis, the field-work was well organized but there were necessarily many unsolved problems associated with different phases of the work. The solution of these problems has been going on steadily since that time and during recent years that part of the work which involves improvements in instruments and methods has been given definite consideration in the general program and progress has been accelerated. The present status of the solution of some of the more important problems and brief descriptions of a few of the improved methods are outlined below.

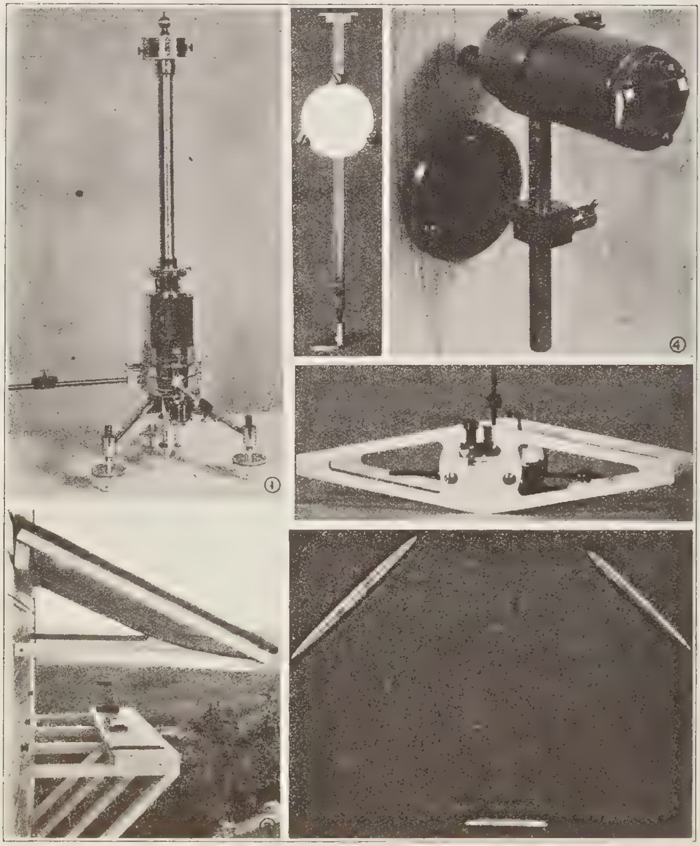
(1) *Temperature-compensation of intensity-variometers*[1]—The horizontal-intensity and vertical-intensity variometers at all the observatories have been compensated for temperature by the magnetic method. Usually this work has been carried out at the Cheltenham Magnetic Observatory and the records from the variometers undergoing tests compared carefully with the records from the standard instruments. From these results the position of the compensation-magnet for true compensation at another observatory is estimated. After the variometer is installed at another observatory its compensation is checked at once by operation at different temperatures obtained artificially. Also the compensation is checked by noting the changes in base-lines which may be the result of seasonal changes in temperature. At present the practice is to determine the temperature-coefficients of the compensating and recording magnets to be used on the variometer, using the method of deflections and making allowance for changes in horizontal intensity during the observations and if necessary for distribution-coefficients. The changes in H are scaled from magnetograms and the distribution-coefficients are determined by means of test-deflections with standard spheroidal magnets to be described later. The correct distance at which the compensating magnet should be mounted on the variometer is given by the equation,

$$r^3 = 2\,M\,(q_1 + q_2)/\,H\,q_1$$

in which r is the distance between compensating and recording magnet, M is the magnetic moment of the compensating magnet, q_1 and q_2 are the temperature-coefficients of the compensating and recording magnets respectively, and H is the horizontal intensity in C.G.S. units. At the Honolulu Observatory the value of r was determined from the above

*Publication approved by the Director, U. S. Coast and Geodetic Survey.

[1]G. Hartnell, Terr. Mag., **30**, 117-124 (1925).



FIGS. *A*1-*A*6: *A*1—Horizontal-intensity magnetic variometer, Schulze type, as equipped with temperature-compensation magnet, sensitivity-control magnet, round mirrors on suspension-system, and base-line mirror-support and cobalt-steel recording magnet (now in operation at Sitka Magnetic Observatory); *A*2—Support and shelter for scale-value deflector at San Juan Magnetic Observatory, San Juan, Porto Rico, for use in the determination of scale-values of magnetic variometers; *A*3—Magnetic-mirror system as used on horizontal-intensity and declination magnetic variometers at Sitka Magnetic Observatory; *A*4—Special lamp for flashing time-marks on magnetograms *A*5—Recording magnet of Schulze vertical-intensity variometer (magnet is equipped with Weston pivots, lock-nuts for counterpoises, and round mirror); *A*6—Spheroidal magnets, the pole-distances of which have been determined accurately (these magnets are used in the determination of magnetic moments and distribution-coefficients of other magnets and are made of 36 per cent cobalt magnet-steel)

equation. The installation of the compensation-magnet and subsequent testing of its effectiveness was carried out at the observatory with very little loss of record. The adoption of temperature-compensation at all of the observatories has resulted in material reduction in cost of compilation of results.

(2) *Direct scaling of magnetograms*[2].—The adoption of the method of direct scaling of hourly ordinates on magnetograms, which has been made practical by the introduction of temperature-compensation, has not only eliminated several steps in the reduction of data to a form convenient for publication but has made it possible for the observatory personnel to carry on much of the work formerly done in the Office in Washington.

(3) *Scale-value determinations with a large deflector*[3].—The use of small deflectors mounted on deflection-bars attached to the variometers has been abandoned at all of the observatories and deflections for scale-value determinations are now made with large deflectors (magnetic moments ranging from 7000 to 15000) at deflection-distances ranging from 2.5 to 3.5 meters. At Tucson the *D*-deflections are made on the observatory magnetometer, using the same deflection-distances which are used on the *H*- and *Z*-variometers. The use of the large deflectors has made it unnecessary to apply corrections for distribution and has eliminated entirely the liability of disturbing the variometers while the deflections are being made. This is especially important in the case of the vertical-intensity instrument where the slightest mechanical disturbance may result in a change in base-line or scale-value or both. Extended tests have been conducted for comparison of distribution-coefficients obtained empirically with those determined from theoretical considerations. These tests consisted in observing scale-values with the deflection-bar (carrying a small deflector) of a vertical-intensity variometer set at azimuths of 10°, 20°, 30°, etc., up to 360°.[4]

Scale-values obtained by a large deflector at a long distance and those obtained with a small deflector mounted on the deflection-bar of the instrument have been compared in a long series of observations. For the deflections with the small magnet the bar was oriented at azimuths at which theory indicates the first distribution-coefficient should be zero. The resulting scale-values obtained by the two methods were in close agreement.

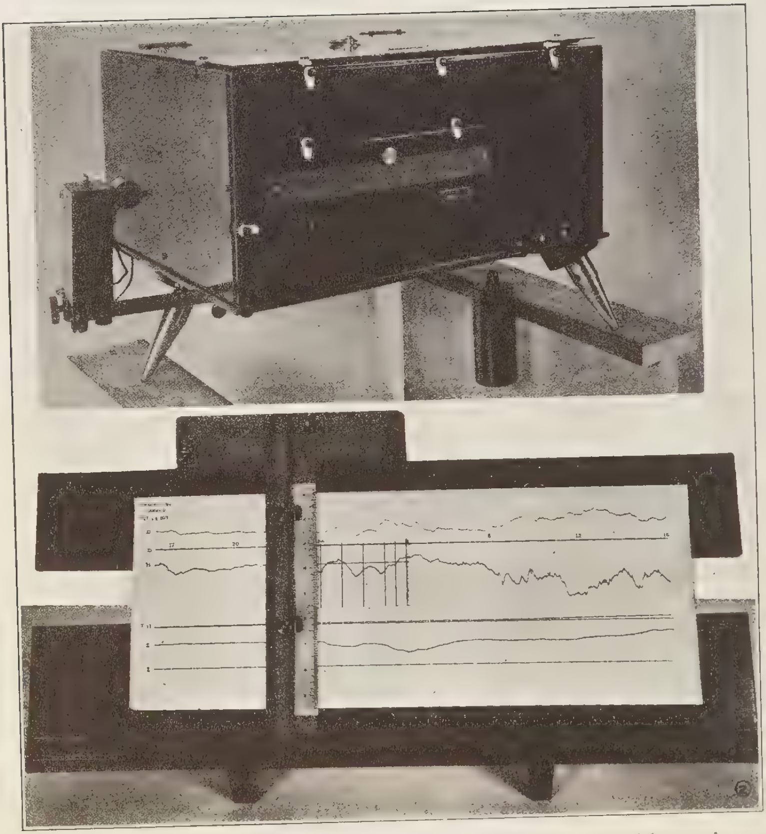
(4) *Quartz-filament investigations*.—Directions for production and manipulation of quartz filaments for use in electrometers and galvanometers have been prepared after detailed study of the methods used at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The filaments are prepared in the usual manner by means of the oxy-hydrogen torch and after selection and measurement are mounted in wooden or brass frames in such a manner as to be available for immediate use in the laboratory or field.

In unifilar horizontal-intensity variometers where the recording magnet is held at right-angles to the Earth's field by the torsion of a quartz fiber, there has usually been considerable difficulty in attachment of the fiber to the torsion-head of the variometer and to the frame which carries the magnet and mirror. It has been the practice, until recently,

[2] W. N. McFarland, Terr. Mag., **31**, 89-95 (1926).

[3] A. K. Ludy, Terr. Mag., **34**, 63-66 (1929).

[4] H. E. McComb, Terr. Mag., **34**, 59-61 (1929).



FIGS. $B1$ AND $B2$: $B1$—Magnetograph-recorder equipped with gravity-driven clock and special relay for widening slit in front of lamp each hour for making time-marks on magnetograms; $B2$—Equipment for use in the direct scaling of hourly ordinates of magnetograms, showing reading-glass, aluminum scale, scale-holder, and reading-board

simply to attach the ends of the filament to the supporting lugs by means of fused shellac. As the hardness of the shellac varies considerably with temperature and humidity, there is usually an irregular drift of the magnet for some months beginning immediately after installation of a fiber. After some experimental work it was decided that this trouble due to drift might be eliminated by bending the tips of the filaments at right-angles before attachment to the lugs with shellac. Variometers with fibres so treated have given quite satisfactory performance from the time of installation. It is believed that the method used in the La Cour[5] instruments may prove to be superior however and is probably less difficult of execution.

(5) *Vertical-intensity variometer pivots and planes*[6].—Originally the Coast and Geodetic Survey vertical-intensity variometers of the Schulze type were equipped with agate cups in which the steel pivots of the recording magnets rested during normal operation. In all but one of the variometers now in routine operation the cups have been replaced by agate planes and the recording magnets equipped with standard Weston pivots. These changes have resulted in more satisfactory performance and greater stability, so that there have been less frequent abrupt changes in base-lines and scale-values.

(6) *Variometer-mirrors*.—As opportunity permits, round mirrors are being substituted for rectangular ones on the recording magnets and on the base-line mirror supports. The use of the round mirror makes it possible to improve the quality of the images by adjustment of the mirror on its axis.

(7) *Scale-value "a-factor" determinations*[6].—For the usual type of unifilar H-variometer the scale-value normally increases with ordinate, that is, with increase in torsion of the fiber. It has been the practice to compute this factor from routine scale-value determinations, which, over long periods of time would fall at a wide variety of ordinates. Since the adoption of direct scaling of hourly ordinates on the magnetograms and the installation of new fibers on some of the variometers and the adoption of temperature-compensation, it is desirable to know this factor at once in order that suitable scales might be prepared. The practice at present in the determination of the "a-factor" is to alter the field at the center of the H-variometer, over a wide range, by means of a large auxiliary deflector placed in the magnetic meridian north or south of the variometer, with north end of deflector north or south, and determine the scale-value for the different positions of the suspended magnet. In a comparatively short time sufficient data of the required accuracy can be obtained for the computation of the desired factor. At Cheltehnam the "a-factor" has been reduced to a negligible quantity on the Eschenhagen H-variometer by the selection of a fiber having a large scale-value and then reducing the scale-value by the desired amount through the use of a control magnet[7].

(8) *Induction coefficients*[8].—A special apparatus for the determination of induction-coefficients of magnetometer-magnets of the India Survey

[5]D. la Cour and V. Laursen, Copenhagen, Inst. Met., Comm. Mag., No. 11 (1930).

[6]H. E. McComb, Terr. Mag., **33**, 65-78 (1928).

[7]G. Hartnell, Horizontal-intensity variometers, U. S. Coast Geod. Surv., Spec. Pub., No. 89, p. 29 (1922).

[8]H. E. McComb. Terr. Mag., **34**, 241-247 (1929).

pattern and for experimental verification of certain formulæ involved in the computation of results, has been designed and constructed and is used in standardization observations. It has been found that for maximum accuracy by this method the vertical distance of the deflector above the suspended magnet should be just one-half the horizontal distance between these magnets.

(9) *Spheroidal magnets*—Three spheroidal, cobalt-steel magnets of different lengths have been constructed for special studies at Cheltenham. The pole-distances of these magnets have been accurately determined and they are now used for the determination of pole-distances and magnetic moments of other magnets by deflections. These magnets are so designed that they may be used with the optical system of the short magnet of an India Survey magnetometer.

(10) *Earth-inductor operation*—In addition to the earth inductors in use at the observatories, inductors of the type designed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington are now in use in the field. These instruments are far more satisfactory than the ordinary dip circle, although it is necessary to use the latter at times when the inductors are not available. At Cheltenham, special studies have been conducted in order to determine errors in dip involved in ex-meridian observations, errors due to improper adjustment of the commutator-brushes, etc. The standard earth inductor at this Observatory is equipped with adjustable brushes and it is standard practice to make routine observations when the brushes are set in their normal position, that is, when the line joining the points of commutation is in the meridian and when the brushes are set at right-angles to this position. When the galvanometer indicates zero current as the coil is rotated for both positions of the brushes, the axis of the coil is actually coincident with the line of true dip. In addition to the true dip from the readings of the vertical circle, a very accurate value of magnetic declination may be

FIG. C1—Test of temperature-compensation of horizontal-intensity variometer at Honolulu Magnetic Observatory, July 27, 1932 (base-line determinations during intervals indicated by dotted lines immediately before and after sudden 7-degree change of temperature of variometer indicates that the instrument is compensated)

obtained from the horizontal-circle readings. It is believed that this method is of importance in inclination-observations with earth inductors and should be given more consideration in the design of field and observatory instruments.

(11) *Galvanometers*—Field galvanometers of the type designed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington are used in field-work in connection with the determination of dip with an earth inductor. Instruments of the Broca type with some modifications and improvements are being supplied observatories when replacements become necessary.

(12) *Magnetometers*—The observatory magnetometers of the India Survey type have been equipped with new, 7-inch horizontal circles with verniers reading to 10 seconds. The regular field magnetometers are also being equipped with new theodolites having 4-inch vertical and horizontal circles and other minor improvements to the optical systems have been made.

(13) *Time-marks on magnetograms*—The plan of flashing time-marks across the magnetograms every hour (or at more frequent intervals) as devised by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington is being adopted for all of the recorders recently constructed. Accurate time for operation of the mechanism is assured by the use of pendulum-clocks and troublesome mechanical devices have been eliminated from the new recorders. At Tucson and San Juan, the time-marks are made photographically by simply widening the slit of the lamp each hour, but it is believed that this method is inferior to one described above. On the grams of the Adie instruments at Cheltenham the marks are produced by deflection of the recording magnets by a very slight amount each hour by electromagnetic methods, the circuit being closed hourly by means of a pendulum-clock. This method has been used at Potsdam and is quite satisfactory.

(14) *Test-deflections for variometers*[9]—An elaborate series of test-deflections of variometer-magnets has been carried out at Cheltenham for the purpose of experimental verification of certain formulæ and for practical purposes in connection with the orientation of recording magnets of variometers. For example: It is now possible at this Observatory, by a very simple means, to orient the H recording-magnet accurately in the magnetic prime vertical, an operation that is usually carried out with considerable difficulty and uncertainty. In addition to these tests a number of tests have been carried out with the Adie instruments in order to determine the most suitable orientation of the deflection-bars in scale-value determinations.

(15) *Magnetograph-recorders* New recorders equipped with both gravity- and spring-clocks have been used. In both types it has been found that the peripheral speed of the drum is not uniform even though the rate of the driving clock as indicated by the second hand may be quite small and uniform. It is believed that this trouble has been traced to lack of uniformity of gear teeth. A new type of recorder is now being tested in which a spring-clock is mounted within a cast aluminum drum, the clock rotating with the drum, as in the United States Coast and Geodetic Survey portable tide-gauge recorder. The new recorders are equipped with electric lamps which are operated from air-cells or storage-

[9]Geo. Hartnell, Terr. Mag., **36**, 279-296 (1931).

batteries. Straight-filament galvanometer lamps are used on the new recorder at Sitka Observatory. This instrument also has the equivalent of two light sources (Stellite mirrors set at 45° on either side of the lamp) one being used for the regular spot and the other for the reserve. This method has made it possible to provide a reserve spot for the vertical-intensity variometer which is important in high magnetic latitudes.

(16) *Magnetochronograph*[10].—The period of a magnetometer-magnet when oscillating under the directive force of the horizontal component of the Earth's field has been quite accurately determined by means of the magnetochronograph. It consists essentially of an intense light-source which is directed toward the glass scale on one end of the magnetometer-magnet and after reflection is brought to focus on a photoelectric cell. As the magnet oscillates the image transits the slit in front of the sensitive cell. By means of a suitable amplifier the photoelectric current is made to operate a sensitive relay which in turn operates the pen of a chronograph. From the resulting chronogram may be scaled, to a high degree of accuracy, the period of the oscillating system. The method is useful in the determination of moments of magnets and in the estimation of personal equation involved in the usual eye-and-ear method in oscillations.

(17) *Humidity-problem at San Juan Observatory*.—At the San Juan Observatory magnetic variometers and other instruments are maintained in continuous operation with great difficulty on account of the excessive humidity which prevails during the greater part of the year. It has been necessary to deal with each instrument individually and many ingenious devices have been perfected at this Observatory for dealing with this vexing problem.

(18) *Field observations*.—Magnetic field-parties and instruments are now transported by trucks equipped with closed bodies. This method simplifies greatly many problems connected with the work and makes it possible for the Chief of Party to plan and execute his work on more definite schedule.

[10] H. E. McComb and C. Huff, Terr. Mag., **34**, 123-141 (1929).

United States Coast and Geodetic Survey,
Washington, D. C.

EARTHQUAKES RECORDED BY MAGNETOGRAPH

By Daniel L. Hazard

The illustration shown herewith is a copy of a portion of a magnetogram from the magnetic observatory of the Coast and Geodetic Survey at Cheltenham, Md., giving a record of the Mexican earthquake of June 3, 1932. The record of the horizontal intensity variometer, in the center, is particularly sharp and shows the preliminary phases, the long waves, and several after shocks. Because of the slow rotation of the drum (20 mm per hour) accurate timing of the phases is impossible, but the measured time of beginning differs by only a fraction of a minute from the time given by the seismograph at Georgetown University.

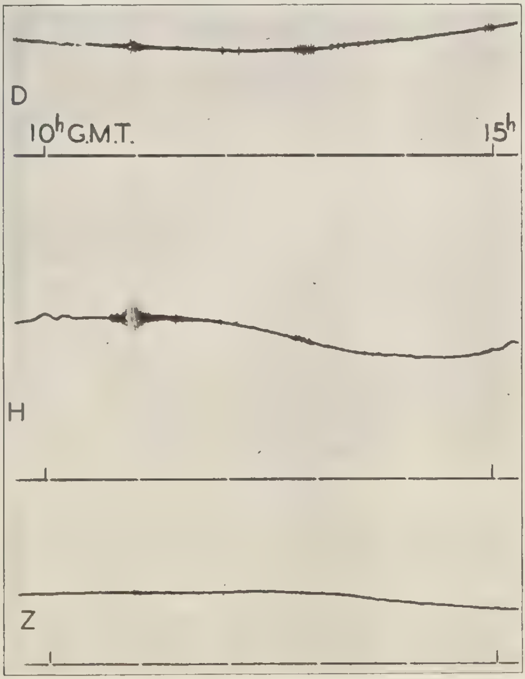


Fig. 1 —Mexican earthquake of June 3, 1932, recorded on magnetograph at Cheltenham, Maryland

It is interesting to note in this connection that the seismological work of the Coast and Geodetic Survey was started in 1903 by Bauer, at that time in charge of the magnetic work of the bureau, in order to compare the earthquake records of magnetographs and seismographs and

determine whether or not the movement of the magnets was entirely mechanical.

It was noticed more than half a century ago that peculiar disturbances were sometimes found on the records of magnetic variometers at about the time of an earthquake. It was at first thought that the earthquake gave rise to a magnetic disturbance, but when the times of disturbance as recorded at different observatories were compared, it was found that it was transmitted through the Earth at just about the same velocity as the surface earthquake-waves. However, it was difficult to explain how an earthquake tremor could produce a rotary motion of the suspended magnets.

Further study of the subject seemed desirable and Bauer arranged for the installation of Bosch-Omori seismographs at the magnetic observatories at Cheltenham, Maryland, Vieques, Porto Rico, and Sitka, Alaska, and for the transfer of an old type Milne seismograph from Oahu College to the Honolulu Observatory, thus providing means for direct comparison of the two types of earthquake record.

A preliminary discussion of the results was made by J. E. Burbank in 1905 in his paper "Earthquakes recorded on the magnetographs at the observatories of the United States Coast and Geodetic Survey." [1] Bauer carried the investigation further in "Magnetograph records of earthquakes with special reference to the San Francisco earthquake of April 18, 1906." [2] These investigations showed that some earthquakes are recorded on the magnetograph and not on the seismograph and vice versa.

Later Professor Harry Fielding Reid of Johns Hopkins University attacked the problem from the mathematical side and showed in his paper "The free and forced vibrations of a suspended magnet" [3] that under conditions such as exist in magnetic variometers a rotary motion would be given to the suspended magnet by earthquakes waves, due primarily to the fact that the center of gravity of the magnet-system does not lie in the axis of rotation.

The earthquake records from these seismographs, though of inferior quality according to modern standards, constituted an important contribution to the study of earthquakes in the United States. Later when the importance of the subject was recognized, the Coast and Geodetic Survey was selected as the organization best equipped to carry on seismological investigations in this country.

[1]Terr. Mag., **10**, 113-128 (1905).

[2]Terr. Mag., **11**, 135-144 (1906).

[3]Terr. Mag., **19**, 57-72, 189-203 (1914).

United States Coast and Geodetic Survey,
Washington, D. C.

MAGNETISCHE VERMESSUNGEN IN DEUTSCHLAND

Von K. Haussmann

Vor einem Jahrhundert waren es hauptsächlich A. von Humboldt, W. Weber und C. F. Gauss, und G. Erman, die in Deutschland das Interesse für erdmagnetische Forschung in weiten Kreisen wachgerufen haben. Gauss und Weber haben im Jahre 1833 in Göttingen ein vollständiges magnetisches Observatorium errichtet. Gauss hat für den Erdmagnetismus eine feste mathematische Grundlage geschaffen.[1] Für die magnetische Feldmessung hat J. Lamont Instrumente und Methoden geschaffen und in Deutschland und im westlichen Europa grosse Messungen ausgeführt.[2] Eine Ergänzung für Bayern hat Neumayer gegeben.[3] Dann trat in Deutschland ein längerer Stillstand ein und erst vor fünfzig Jahren zeigte sich eine neue Belebung der magnetischen Forschung. In Wilhelmshaven wurde 1878 das Marine-Observatorium in Betrieb genommen und von dort aus wurde in Nordwest-Deutschland eine Vermessung ausgeführt.[4] Der eigentliche Anfang der neueren magnetischen Arbeiten ist aber auf die Errichtung des Observatoriums auf dem Telegraphenberg bei Potsdam im Jahre 1888 zurückzuführen. Hier wurde eine Stelle geschaffen, die der Bezugspunkt für die magnetische Vermessung aller deutschen Bundesstaaten geworden ist.[5] Damit ist die Einheitlichkeit der neueren Aufnahmen erreicht worden. Wegen Störung durch elektrische Bahnen in Potsdam ist 1907 eine Hilfsstation mit laufender Registrierung in Seddin südlich von Potsdam eingerichtet worden, und nachdem auch dieser Ort durch elektrischen Bahnbetrieb gestört wurde, ist 1930 ein vollständig neues Observatorium in Niemegk, 45 km südwestlich von Potsdam, geschaffen worden.[6] Dieser Ort liegt in einer vom Verkehr abgewandten industriefreien Gegend, so dass anzunehmen ist, das dortige Adolf Schmidt-Observatorium werde für lange Zeit der Stützpunkt der magnetischen Forschung in Deutschland bleiben können.

Von der Magnetischen Abteilung des Preussischen Meteorologischen Instituts aus erfolgten die Landesaufnahmen in Norddeutschland und in Südwest-Deutschland. Württemberg und Sachsen haben ihre Landesvermessungen unmittelbar an Potsdam angeschlossen. Bayern hat sein Münchener Observatorium benützt, den Anschluss an Potsdam aber durch gleichzeitige Vergleichsmessungen erreicht und später auch Anschlussmessungen in Potsdam ausgeführt.

Die Entfernung Potsdams vom südlichen Teile Deutschlands ist zu gross, um die Variationen mit der bei den Messungen angestrebten Genauigkeit sicher erhalten zu können. Das von Lamont 1840 in München eingerichtete und 1898 wieder in Betrieb gesetzte Observatorium wäre seiner geographischen Lage nach für den ganzen südlichen Teil günstig gewesen; aber es war durch Strassenbahnen etwas gestört. Deshalb wurden für die zeitlich auseinanderliegenden Vermessungen der südwestlichen Bundesstaaten temporäre Hilfsobservatorien errichtet: für Württemberg in Kornthal bei Stuttgart, für Südwest-Deutschland Oberjägerhof bei Strassburg und später für Hessen Apfelbachbrücke bei

[1] Gauss, Allgemeine Theorie des Erdmagnetismus 1839, Ges. Werke, Band 5.

[2] Lamont, Handbuch des Erdmagnetismus (Berlin 1849). Ders., Magnetische Karten von Deutschland (München 1854)

[3] Neumayer, Magnetische Vermessung der Rheinpfalz 1855/56 (Dürkheim 1905)

[4] Eschenhagen, Bestimmung der erdmagnet. Elemente an 40 Stationen im nordwestl. Deutschland (Berlin 1890).

[5] Das Met.-Magnet. Observatorium bei Potsdam. Preuss. Met. Inst. (Berlin 1912).

[6] Ad. Schmidt, Das Variationshaus in Niemegk. Tät.-Bericht 1930, Met. Inst. (Berlin 1931).

Gräfenhausen unweit von Darmstadt. Für magnetische Feldstationen wurden durchweg trigonometrische Punkte und Richtungen der Landesaufnahmen gewählt, mit Ausnahme von Bayern, wo unvermarkte Punkte genommen und die Azimute astronomisch bestimmt worden sind.

Die magnetische Aufnahme Norddeutschlands wurde 1898 bis 1903 ausgeführt auf 265 Stationen in durchschnittlich 40 km Abstand.[7] Es war geplant, dieser Vermessung eine eingehendere in 18 km Stationsabstand und eine weitere in 10 km Abstand folgen zu lassen und zur Klärung von Unregelmässigkeiten in der örtlichen Verteilung besonders für Geologie und Topographie noch weitere Einzeluntersuchungen anzuschliessen. Dieser Plan konnte aber wegen fehlender Mittel nicht weiterverfolgt werden und auch in absehbarer Zeit wird dies nicht möglich sein.

Württemberg wurde nach dem Plane von August Schmidt mit 65 Stationen in 20 km Abstand im Jahre 1900 magnetisch vermessen.[8]

In Südwest-Deutschland wurde, ähnlich wie in Norddeutschland, eine Vermessung in 40 km Stationsabstand im Jahre 1906 ausgeführt, wobei nach Hessen 9 Punkte, nach Baden 14 und nach Elsass-Lothringen 16 Punkte fielen.[9]

Bayern, das erstmals von Lamont in 240 Punkten vermessen war, wurde von 1903 bis 1911 in 187 Stationen neu aufgenommen.[10]

Die magnetische Landesaufnahme von Sachsen erfolgte 1907 auf 100 Stationen, mit Skassa als Kontrollstation; eine Spezialvermessung auf 22 Punkten wurde später angeschlossen.[11]

Eine eingehende Vermessung auf 56 Stationen in Hessen[12] wurde 1910/11, eine solche in der Rheinpfalz[13] 1927-28 auf 60 Punkten vorgenommen. Beide Länder haben stark gestörte Gebiete.

In magnetisch gestörten Gebieten wurden vielfach Spezialaufnahmen ausgeführt. Von grösseren vollständigen Messungen seien genannt die im Küstengebiet der Ostsee[14] und der Nordsee[15], des Harzes[16], Ries[17] und Bayrischen Waldes.[18]

Von ungemein grosser Ausdehnung ist das von Norden und Osten her sich weit über das Küstengebiet der Ostsee in das Land hineinziehende Störungsgebiet. Zu dessen Klärung führt das Reichsamt für Landesaufnahme bei trigonometrischen Messungen zugleich Deklinationsbestimmungen aus; allein in West- und Ostpreussen wurde von 1905 bis 1913

[7]Ad. Schmidt, Magnet. Karten von Norddeutschland für 1909 nach der von Eschenhagen und Edler ausgeführten Landesaufnahme des Königreichs Preussen. Met. Inst. (Berlin 1910). Ders., Die Magnet. Vermessung I. Ordnung des Konigreichs Preussen nach den Beobachtungen von Eschenhagen und Edler (Berlin 1914).

[8]Haussmann, Die magnet. Elemente von Württemberg und Hohenzollern. Statist. Landesamt (Stuttgart 1903).

[9]Nippoldt, Magnet. Karten von Südwest-Deutschland für 1909. Met. Inst. (Berlin 1910).

[10]Messerschmitt, Magnet. Ortsbestimmungen in Bayern. Mitt. I-III. (München 1905, 06, 08). Burmeister, Erdmagnet. Landesaufnahme von Bayern nach den von Messerschmitt 1903-11 ausgeführten Beobachtungen (München 1928).

[11]Göllnitz, Die magnet. Vermessung des Sächsischen Staatsgebietes (Freiberg 1919).

[12]K. Schering und A. Nippoldt, Erdmagnet. Landesaufnahme von Hessen (Darmstadt 1923).

[13]Burmeister, Erdmagnet. Vermessung der Rheinpfalz (München 1932).

[14]W. Schaper, Magnet. Aufnahme des Küstengebiets zwischen Elbe und Oder. Hamburg 1889.—Teil 2, Schleswig (Lübeck 1909).

[15]Schück, Magnet. Beob. auf der Nordsee und an der Nordsee- und Ostsee-Küste (Hamburg 1893 und 1901).

[16]Eschenhagen, Magnet. Untersuchungen im Harz (Stuttgart 1898).

[17]Haussmann, Magnet. Messungen im Ries und Umgebung (Berlin 1904).

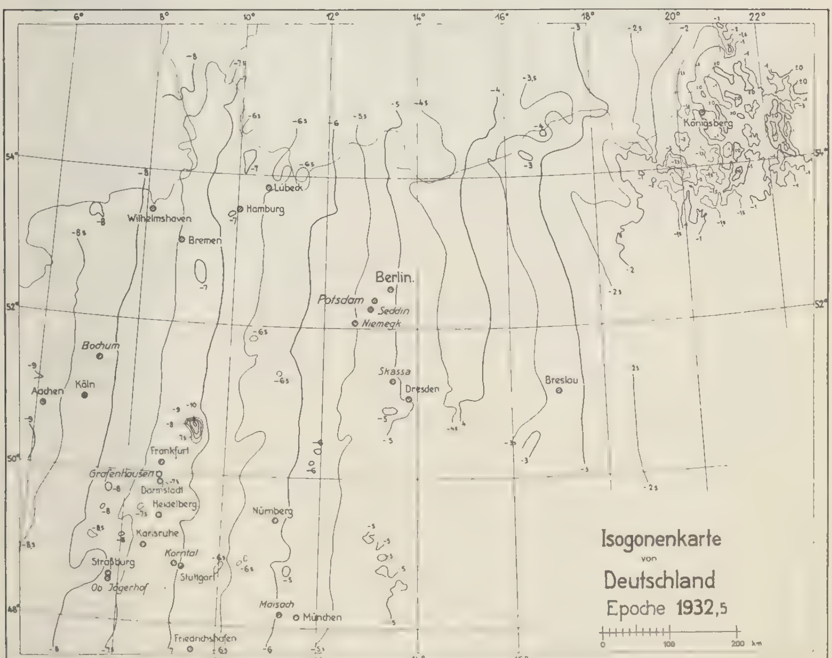
[18]Stöckl, Erdmagnet. Messungen im Bayrischen Wald (München 1922).

auf 4570 Punkten gemessen.[19] Die Marineleitung führt an Küsten und auf der Ostsee magnetische Messungen aus.

Die Nennung weiterer magnetischer Arbeiten würde den verfügbaren Raum überschreiten; es kann hierfür auf die Zusammenstellung in Hellmanns magnetischer Kartographie verwiesen werden.[20]

In neuer Zeit werden vielfach Messungen der Vertikalintensität in Störungsgebieten für geologische Zwecke ausgeführt; sie können leicht und rasch vorgenommen werden mit der magnetischen Feldwage von Ad. Schmidt.[21]

Zusammenfassend kann man sagen, dass die magnetischen Vermessungen in Deutschland so weit ausgedehnt sind, dass man für das ganze Gebiet Isogonenkarten mit einer für die Praxis ausreichenden Genauigkeit herstellen kann.[22] Für Karten der Isoklinen und Isodynamen bestehen in Störungsgebieten noch vielfach Unklarheiten.[23] Das hier beigefügte Isogonenkärtchen ist nach den deutschen Vermessungen innerhalb der früheren Grenzen des Deutschen Reiches entworfen.



Für die Fortführung der magnetischen Arbeiten werden in Deutschland auf einigen Säkularstationen von Zeit zu Zeit Wiederholungsmessungen gemacht. An vollständigen Magnetwarten ist jetzt nur das

[19] Ad. Schmidt, Die magnet. Deklination in West- und Ostpreussen nach Messungen der Trig. Abt. der Landesaufnahme (Berlin 1922).

[20] Hellmann, Magnetische Kartographie in historisch-kritischer Darstellung. Met. Inst. (Berlin 1909).

Adolf Schmidt-Observatorium in Niemegk vorhanden. Für Süddeutschland ist es wichtig, dass anstelle des eingegangenen Münchener Observatoriums eine Magnetwarte bei Maisach, 25 km westlich von München entsteht, deren Einrichtung bei der finanziellen Not freilich erst langsam geschaffen werden kann. Auch in Gross-Raum bei Königsberg wird nach und nach eine magnetische Warte eingerichtet. Für Registrierung der Deklination waren früher 3 bergmännische Warten vorhanden; jetzt registriert nur noch eine in Langenberg bei Bochum.

Die magnetischen Landesaufnahmen im Deutschen Reich sind zum grössten Teil nun schon 30 Jahre alt, es wäre an der Zeit sie neu durchzuführen; besonders die Verwendung des Erdinduktors statt des Nadelinklinatoriums macht die Neumessung wünschenswert. In Preussen ist auch schon damit begonnen worden.[24] Die Fortsetzung dieser Neumessungen wird aber bei unseren misslichen finanziellen Verhältnissen für lange Zeit nur in ganz geringem Umfang möglich sein.

Ausser den genannten magnetischen Arbeiten, die in Deutschland selbst zum Austrag gekommen sind, haben noch grössere magnetische Messungen auswärts stattgefunden, die aus dem Potsdamer Observatorium hervorgegangen oder von hier aus unterstützt worden sind. So haben der Eschenhagen-Tesdorpfsche Magnettheodolit[25] und die Schmidtsche Feldwage auch ausserhalb Deutschlands vielfach Verwendung gefunden. Viele hervorragende Forscher haben in Potsdam ihre magnetischen Reiseaufnahmen vorbereitet. Die Deutsche Südpolar-Expedition 1901/03 hat grosse magnetische Forschungsarbeit geleistet;[26] auf ihr ist der Bidlingmaiersche Doppelkompass entstanden, der sich bei Beobachtungen auf See und in der Luft bewährt hat.[27] Dank der Stiftung der Carnegie-Institution, die neuerdings den Bau eines Doppelkompasses ermöglicht hat, konnten auf der Arktisfahrt des Luftschiffs "Graf Zeppelin" 1931 viele Beobachtungen angestellt werden.[28] Von deutscher Seite sind grössere magnetische Arbeiten auf Samoa, Island, und in Zentralasien ausgeführt worden.[29, 30]

So hat auch Deutschland mitgewirkt bei der von Bauer in grösster Ausdehnung begonnenen und geleiteten Aufgabe, die magnetische Vermessung der Erde auf dem Wasser und zu Lande zu vervollständigen.

[21]Ad. Schmidt, Ein Lokalvariometer für die Vertikalintensität, 1. und 2. Mitt. Tät.-Bericht des Met. Inst. 1914 und 1915.

[22]Haussmann, Isogonenkarte vom Deutschen Reich für 1925 (Charlottenburg 1925).

[23]Haussmann, Die magnet. Landesaufnahmen im Deutschen Reich und magnet. Uebersichtskarten von Deutschland für 1912. Petermanns geog. Mitt., **59**, 11-18 (1913).

[24]Magnetische Arbeiten. Tät.-Bericht Met. Inst. 1931 (Berlin 1932).

[25]Haussmann, Der Magnettheodolit von Eschenhagen-Tesdorpf. Zs. Instrumentenk., **26**, (1906).

[26]Bidlingmaier, Erdmagnetismus. Deutsche Südpolar-expedition V. Berlin (1925). Luyken, Kerguelen-Station. Ebenda, VI. (1908).

[27]Fanselau, Ueber Messungen mit dem Doppelkompass. Tät.-Bericht Met. Inst. (Berlin 1931). Ders. Messungen mit dem Doppelkompass im Luftschiff. Z. Arktis, **4**, 14-18 (1931).

[28]Ljungdahl, Preliminary report of the magnetic observations made during the aeroarctic exped. of the "Graf Zeppelin" 1931. Terr. Mag., **36**, 349-355 (1931).

[29]Angenheister, Samoa-Observatorium Berlin 1911 und 1914. Ders., Island-Expedition 1910. Göttingen 1911.

[30]Venske, Filchners erdmagnet. Beobachtungen in Zentralasien 1926/28. Met. Inst. (Berlin 1931).

Schwäbisch Gmünd, Deutschland

MAGNETIC WORK OF THE DOMINION OBSERVATORY, OTTAWA, CANADA, 1907-32

By C. A. French

The decision to make the September issue of the Journal a memorial number in honor of Dr. Bauer, the greater part of whose life was devoted to the study of problems relating to the Earth's magnetism, is to be commended. On account of his great interest in magnetic work in Canada as well as that carried on by organizations generally, it seems fitting that a review be given of the work of the Dominion Observatory, touching upon some of the problems encountered in an endeavor to make a systematic magnetic survey of the Dominion of Canada. It is, moreover, considered as an opportunity of paying some slight tribute to the memory of Dr. Bauer, who, in Canada, was so well known as a scientist and highly esteemed as a man.

In tracing the history of terrestrial magnetism, or for that matter any other line of endeavor, it is noted that with every advance there is invariably the personal as well as the historical aspect. Thus it is that our knowledge of the declination of the compass is credited to Columbus; with the announcement in 1600 that the Earth itself is a great magnet is associated the name of Gilbert; Halley, who realized the practical importance of the science, was responsible for the first chart of magnetic declination which appeared in 1701; and with the impetus given to the study of terrestrial magnetism during the first half of the nineteenth century is associated the name of Gauss, especially noted for his theoretical discussions in which he was ably assisted by Humboldt, Sabine, and other eminent investigators whose record of achievement was a fine example of cooperative effort.

The beginning of the present century, or possibly a few years before, witnessed a fresh revival of interest in the study of the Earth's magnetism and related phenomena. Throughout the intervening period the name of Louis A. Bauer, late Director of the Department of Terrestrial Magnetism of the Carnegie Institution, is probably the best known of the many whose names, too, will be recalled when reviewing the progress during the first half of the twentieth century. Not only did he contribute to the theoretical discussions, but as a result of his organizing ability and enthusiasm there has accumulated a vast amount of observational data so essential for practical purposes as well as for the study of the Earth's magnetism. That he was very successful in his efforts to bring about cooperation between the organization of which he was for so long head and foreign organizations, including governments, is quite well known. With his passing there will be added another name to a list of scientists, the records of whose lives are an inspiration to succeeding generations.

The status of the magnetic work in Canada at the beginning of the present century may be briefly summarized. In addition to the practically continuous records since 1843 at what was known until 1898 as the Toronto Magnetic Observatory and since that date as the Agincourt Magnetic Observatory, there were many observations dating from as early as 1600. Unfortunately these were of a non-homogeneous character; many different individuals and organizations were responsible for the

observations, and many of the observations, though representing a certain locality, were not correlated, so that full use could not be made of them to investigate phenomena such as secular change. The Topographical Survey, Department of the Interior, had been accumulating data, chiefly declinations, in Canada since 1880 in conjunction with their land-survey operations, confined up to this time to Western Canada but to extend later over the entire country. During the first decade of the present century the Meteorological Service, in addition to maintaining the observatory at Agincourt, was responsible for important surveys in Northern Canada including a survey in the sub-polar regions in 1908-09, and a survey along Mackenzie River in 1910. In 1912 an expedition operated in Hudson Bay and Hudson Strait. In accordance with the policy of the Department of Terrestrial Magnetism of the Carnegie Institution of making surveys in regions where reliable data were lacking, this organization sent numerous expeditions into Canada between 1905 and 1913. Many of the observations were made personally by Bauer. The activities of the Carnegie Institution doubtless stimulated the interest of the then Director and Assistant Director of the Dominion Observatory, the late Dr. King and the late Dr. Klotz, in the problems of terrestrial magnetism, though there is evidence that they were both alive to the importance of geophysical investigations, as seismological instruments were installed in the Observatory in 1906, and a complete magnetic outfit made by Tesdorpf was purchased in 1900. It is safe to assume, however, that Bauer's influence was felt through the medium of the Journal of Terrestrial Magnetism, for the publication of which he was so long responsible, and also on account of his work as head of the Division of Terrestrial Magnetism of the United States Coast and Geodetic Survey. As a result of the desire on the part of the Canadian scientists to make some contribution to the study of the problems relating to the Earth's magnetism, as well as to obtain data for practical purposes, a systematic survey was inaugurated by the Dominion Observatory in 1907.

The intention of those responsible for the survey was to cover the country, eventually, with a net-work of stations at each of which was to be obtained a value of the three magnetic elements, declination, inclination, and horizontal intensity. The results were to be obtained with instruments of the most approved type, so that they could be used for scientific as well as practical purposes. There was, moreover, a desire to cooperate in every way possible in any program of investigation of a national or international character. This policy has been continued by the present Director, R. Meldrum Stewart.

The land area of Canada is approximately 3,600,000 square miles, being slightly greater in extent than the United States of America including Alaska. To cover the country with stations having a distribution comparable with that usually aimed at where surveys have been made, would entail considerable cost. With limited resources available it was out of the question to attempt to complete the survey in a season. As the work progressed it has been necessary to keep a check on the secular change of the elements so that the observations can be reduced to any desired epoch. Many obstacles have been encountered, though possibly the seriousness of these was not fully realized at the outset. Considerable of the country could be reached only by canoe, so that it was impossible

to have a uniform distribution of stations. This might be overcome to a large extent if the aeroplane were adopted as the means of transportation. In northerly latitudes it is found that more time is required to complete the observational program on account of disturbances.

The work was begun by occupying stations in the more settled parts of the country mainly along railway lines and water routes to facilitate the problem of transportation. When the canoe was resorted to it was frequently felt that the scientific data obtained were disproportionate to the expenditure of finances and energy. The following table will give an idea of the distribution of stations occupied between 1907 and 1931. The difference between "Station-occupations" and "Localities" represents for the most part the number of occupations of repeat-stations; comparatively few localities are represented by more than one station.

TABLE 1—*Dominion Observatory magnetic stations, 1907–31*

Geographical divisions	Station-occupations	Localities
Labrador[1]	4	4
Newfoundland[1]	2	2
Prince Edward Island	10	5
Nova Scotia	50	29
New Brunswick	29	20
Quebec	193	113
Ontario	326	185
Manitoba	117	75
Saskatchewan	81	45
Alberta	120	83
British Columbia	118	67
Yukon Territory	8	8
Northwest Territory	35	22
Total	1093	658

[1]Foreign territory.

The work has been coordinated as far as possible with that of other organizations, notably the Carnegie Institution and the Meteorological Service of Canada by observing at many of their stations. All observations are reduced to International Magnetic Standard, or, prior to the adoption of a final value, the provisional one, by making frequent comparisons with standard instruments at fairly regular intervals. Most of these comparisons were made at Agincourt, the base for Canada. In addition several comparisons were made at Washington with the standards of the Carnegie Institution.

The reason for frequent comparisons with standards was not on account of failure to get satisfactory results from a single series but on account of apparent changes in the instruments. This may be illustrated by an example taken from the comparisons covering the period 1926-31. A comparison of declination was made in November 1927 between the Agincourt standard and magnetometer C. I. W. No. 20. The value obtained for (I.M.S.$-$No. 20) was $-0\overset{'}{.}4 \pm 0\overset{'}{.}04$ from a set of 12 observations. The value of a series made in December 1928 for (I.M.S.$-$No. 20) was $-0\overset{'}{.}9 \pm 0\overset{'}{.}05$ from 15 observations. From these results there is evidence of some instrumental change. For 13 series of

comparisons between 1925 and 1931 the mean value of (I.M.S. − No. 20) is −0′.8 the extreme values being −0′.4 and −1′.0. This illustrates fairly accurately what was obtained with magnetometer P.I.C. No. 104, which is one of the C.I.W. types constructed by Precise Instrument Company. In general what is true of declination applies also to inclination and horizontal intensity.

The declination-comparisons are sufficiently comprehensive to conclude that the discrepancies are in part the result of some change in the standard instrument in spite of the fact that the field instruments may possess a source of error such as was discovered in magnetometer P.I.C. No. 104. It was found that the long magnet, used regularly for declinations, gave a different value for different elevations. From a series of tests the difference in the declination amounted to 0′.8 with the magnet at high and low positions. These positions were such that the cross-line was quite faint, so faint in fact, that an observer familiar with the instrument would at once suspect that there was lack of proper adjustment. The maximum error, therefore, from this source would probably be less than 0′.4. According to Gustaf S. Ljungdahl[1] "the explanation of the various corrections may be found in an irregular refraction in the lens, possibly arising from some deforming tension in the brass frame."

The main concern, possibly, after the observations are obtained is the elimination of the effects of the regular diurnal change and the irregular changes due to disturbances. The records of observatories, ordinarily, greatly facilitate this work; in the case of disturbances they are necessary. In addition to the observatory at Agincourt there is one other which is located at Meanook where it has been in operation since 1916. The survey has already extended to areas where the changes exhibit decidedly local characteristics. Mainly on this account the usual method of reducing the various elements to the mean of the 24 hours is not followed. The practice is to refer declination to the mean of 12 hours. between 7^h and 18^h, L.M.T. These two methods will give results which probably do not differ more than 2.′0. It is immaterial which is used so long as one or the other is followed consistently. As regards inclination and horizontal intensity no attempt has been made to correct for diurnal change. Mean values are obtained from observations taken at fairly definite times both forenoon and afternoon. The mean times are approximately $9^h.8$ and $15^h.6$ for inclination, and $11^h.2$ and $14^h.4$ for horizontal intensity. The results of inclination and horizontal intensity taken according to a definite method show the varied character of the diurnal change. At 20 stations in Eastern Canada occupied in 1931, the morning observations of inclination were, without exception, higher than those of the afternoon, the average difference being 1′.9; the horizontal intensity was greater in the afternoon than in the forenoon, the average difference being 36γ. At 12 stations in Western Canada including the region of Mackenzie River, the morning inclination exceeded the afternoon by 2′.0, and the horizontal intensity of the forenoon was less than the afternoon by 16γ. The corresponding averages for 23 stations occupied in 1923 and representing practically the same locality as the latter were 2′.0 and 9γ. At 41 stations occupied in 1918 between 60° West and 95° West, and south of latitude 50° North the values were 3′.1 for inclination and 47γ for horizontal intensity. The results will suffice to

[1]Terr. Mag., 34, 73 (1929).

show the variation with locality of the horizontal intensity and inclination, though the latter is less apparent; and further, the fact of these differences being almost without exception of the same sign is an indication of the reliability of the observations obtained.

Due to the general practice of observing for declination at fairly regular intervals throughout the day, and at all stations, results are obtained which show the complicated nature of the regular diurnal change and also the irregular changes. The results of the operations of the two seasons 1922 and 1923 illustrate this. During these two seasons 125 stations were occupied. Generally speaking the range of declination was found to increase with magnetic latitude. The results of the diurnal range which was obtained from smoothed curves at seven stations north of latitude 54° North, are given in Table 2, and are representative of results obtained at 23 stations.[2] The range for the corresponding day at Meanook, which was obtained from records very courteously supplied by Sir Frederic Stupart, then Director of the Meteorological Service, is also given. The results at Fort Smith, for example, compared with the corresponding results at Meanook suggest a simple relation between the range of declination and the horizontal force. On two successive days at the former the values were 30'.0 and 14'.5, and for the corresponding days at Meanook were 18'.2 and 9'.0. The computed values in the Table were obtained from the expression $d = d_m H_m H^{-1}$ where d_m is the range of declination and H_m the horizontal intensity at Meanook and H the horizontal intensity at the field station. It will be seen that the observed and computed values are in quite good agreement. It may be pointed out that the time of occurrence of the maximum easterly and westerly pointing of the magnet at stations in the vicinity of Hudson Bay are approximately 1.4 hours in advance of the corresponding phenomena at Meanook, which in turn are about 1.5 hours in advance of those at Aklavik on Mackenzie River, assuming that these maxima occur at the same local mean time.

Though this simple relation seems to hold for the region under consideration, the expression deduced by Bauer,[2] namely, $d = k \sec^2\phi$, where ϕ is the magnetic latitude and deduced from the expression $\tan I = 2 \tan \phi$, was not overlooked. It apparently does not hold for a particular locality and season. For example, the value of k was derived from Meanook data of August 10 and found to be equal to 2.5 using for d and I the values 16'.0 and 77° 54'. This gives for Churchill, where $I = 84° 24'.5$, the value 67', whereas the observed value was 28'.5.

The results of 1922-23 reveal a further difference in the diurnal variation depending upon the locality. Observations on the same day at two widely separated field stations and Meanook show this.[1] This characteristic is shown in Figure 1, which represents seasonal results at Meanook, stations in the region of the Lower Mackenzie, and in Northern Manitoba adjacent to Hudson Bay. The zero corresponds to the mean of twelve hours from 7 to 18. The main features may be briefly summarized. There is a slight difference in the local mean time of the maximum easterly pointing of the magnet, the earliest being in Northern Manitoba and the latest at Meanook. The maximum westerly pointing is reached

[2]Publications of the Dominion Observatory, 8, No. 8, p. 176.

[2]Terr. Mag., 2, p. 70 (1897).

[1]Publications of the Dominion Observatory, 8, No. 8, pp. 163-164.

earliest in Northern Manitoba and almost two hours in advance of that on Mackenzie River.

Table 2—*Diurnal range of magnetic declination at field-stations*

Station	Latitude North	Longitude West	Date	Meanook	Field-station Computed	Field-station Observed	Field-station (O−C)
	° ′	° ′	*1922*	′	′	′	′
Fort St. John.	56 12	120 49	May 22	16.6	16.1	17.0	+0.9
Fort Vermilion	58 24	116 01	June 23–24	15.2	18.3	17.5	−0.8
Resolution B..	61 10	113 40	Aug. 3–4	22.4	33.7	37.0	+3.3
Kettle Rapids.	56 24	94 33	June 1	18.0	29.8	27.0	−2.8
			1923				
Fort Smith...	60 01	111 52	June 20	18.2	27.2	30.0	+2.8
			June 22–23	9.0	13.4	14.5	+1.1
Churchill.....	58 46	94 13	Aug. 10	16.0	33.8	28.5	−5.3
Swampy Lake.	55 15	94 08	Sep. 20	7.8	11.5	16.6	+5.1

From the foregoing results it is apparent that the problem of determining corrections for diurnal change is somewhat complicated. This, however, is less serious than that connected with the elimination of the so-called disturbance effects. In practice it is assumed that the disturbance-change is the difference between the mean value and the observed. It is further assumed that the magnitude of the change due to disturbance is the same at one station as at another and that they occur simultaneously. Generally speaking if the field station is not too far removed from the base-station the results are improved by applying the disturbance-corrections determined from the latter. There is a limiting distance between the base-station and the field station but it is uncertain what it is. There appear to be other factors than distance. Some consideration has been given to this question. For example, during the three seasons 1927-29 twenty-seven stations were occupied and to the observations of declination corrections for disturbance derived from Agincourt were applied. Residuals were derived from the observations both with and without disturbance-corrections. Accepting the average residual as a criterion of accuracy it was found that with one exception the results were improved when corrections were applied. These stations were distributed from Quebec to Wolseley, the former being approximately 450 miles and the latter 1,200 miles from Agincourt; the nearest station was about 250 miles distant. There are instances indicating that disturbances are comparatively local. Thus at Chipewyan, which is about 300 miles northerly from Meanook, the declination on July 2, 1931 at 15^h was 26° 27′.8 East and on July 3 at the same hour it was 26° 16′.8; from a mean curve the value was 26° 20′.0 East. The departure at the base-station, Meanook, at the same absolute time on these two days was 0′.6 and 0′.1 as compared with +7′.8 and −3′.2. This is further illustrated by reference to Figure 2. The diagram represents the observations taken at Norman ($\phi = 64°.9$ N, $\gamma = 125°.6$ W) on July 20, 1923 and values from Meanook records for the same absolute time. The mean value at Norman, excluding disturbed observations, was 41° 29.′0, and that at Meanook 27° 28′.9. The ordinates represent the departure of the declina

tion from the respective mean values. The results are sufficient to emphasize the difficulty of reducing observations at stations remote from the base-station. From a consideration of the diurnal changes and the disturbances there appears to be something decidedly local as regards the operation of the forces causing the latter, whereas in the case of the former it seems to be general.

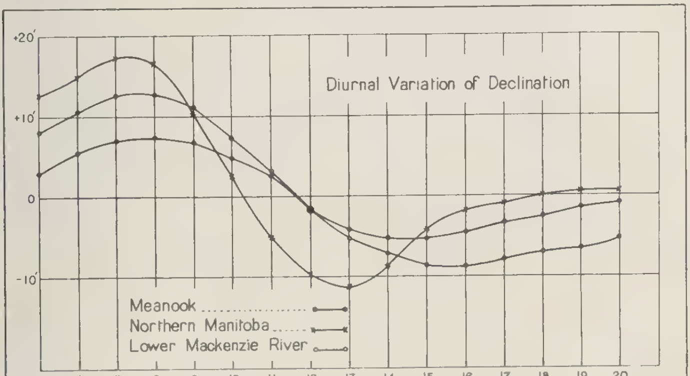


FIGURE 1

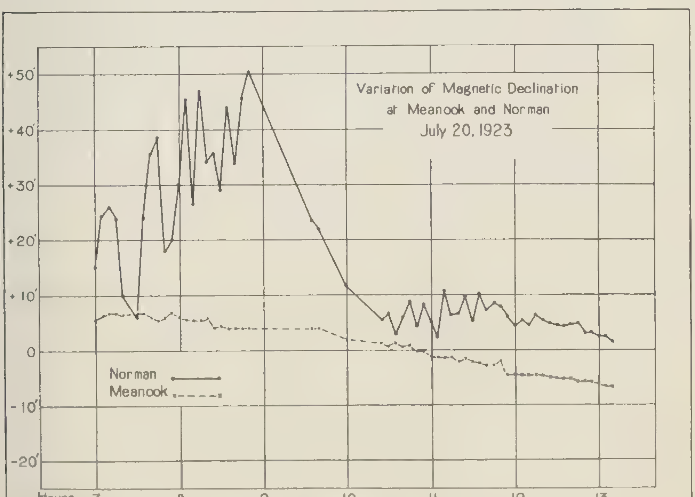


FIGURE 2

From the results obtained during the season of 1928 in the region of Hudson Strait there appears to be evidence that disturbances are much more pronounced in that locality than in regions previously surveyed where the magnetic latitudes differ but slightly, as, for example, at Churchill, York Factory, and other stations near Hudson Bay. Dis-

turbances were so much in evidence that the regular diurnal variation of declination was almost completely masked. The results of that season's operations emphasize the need of having recording instruments for work in that particular region if not in higher latitudes; and in order to obtain data sufficiently accurate, say, for secular change it is necessary to carry out a more extensive program of observations than at stations in lower latitudes. The results suggest further a relation between magnetic perturbations and the aurora, as these stations lie in the belt of maximum auroral frequency.

The program of repeat-observations, which required one year for completion, had this year to be discontinued. The results already obtained, however, will furnish information regarding secular change during recent years over most of the area thus far covered by the survey. The results of repeat-observations obtained at a station in a locally disturbed area may be of interest as they illustrate the apparent difference between the secular change in such a region and that in localities comparatively undisturbed. The results at this station, Savoff (formerly Sabinoff[5]), and, for comparison purposes, two other stations are given in Table 3.

TABLE 3—*Magnetic results showing the effect of local disturbance on secular change*

Station	Latitude North	Longitude West	Period	Av. annual change[1]		
				D	*I*	*H*
	° ′	° ′		′	′	γ
Cochrane...	49 04.0	81 01.6	1914, July to 1928, Aug.	− 5.0	−0.8	− 8
Hearst.....	49 40.9	83 39.6	1914, Aug. " 1926 Aug.	− 5.5	−0.7	− 9
			1926, Aug. " 1930, Sep.	− 4.8	−0.6	− 8
Savoff......	49 56.8	85 01.3	1914, Aug. " 1928, Aug.	−15.0	+0.4	−12
			1928, Aug. " 1930, Sep.	−13.4	+0.1	−12

[1]A negative sign indicates that west declination is increasing, and east declination, north inclination, and horizontal intensity are decreasing.

With the accumulation of data comes the realization of the importance of extending the work to include areas hitherto unexplored magnetically. This will require an expenditure of effort and money by no means inconsiderable. The importance, therefore, of avoiding the accumulation of data beyond that which is necessary to meet the requirements for practical and scientific purposes is apparent. As a guide to the best methods for obtaining data most suitable for the study of problems relating to the Earth's magnetism we turn naturally to sources such as the Department of Terrestrial Magnetism, the JOURNAL OF TERRESTRIAL MAGNETISM, and the Section of Terrestrial Magnetism of the International Union of Geodesy and Geophysics, with all of which Bauer was so closely identified, as reflecting the opinions of the best minds engaged in geophysical research.

[5]Publications of the Dominion Observatory, 5, No. 5, p. 167.

DOMINION OBSERVATORY,
Ottawa, Canada

A DEMONSTRATION OF THE GEOLOGIC POSSIBILITIES OF RESISTIVITY AND MAGNETIC PROSPECTING METHODS

By C. A. Heiland

In his studies of terrestrial-magnetic and atmospheric-electric phenomena, Bauer's interests were not confined to the pure science-problems in these fields. He also gave a great deal of attention to the question as to how the instruments and methods used in terrestrial-magnetic and terrestrial-electric research could be best adapted to the needs of the prospector. The writer in particular has enjoyed his advice and cooperation in a number of problems which arose in the development and calibration of magnetic instruments. While Bauer was Director of the Department of Research in Terrestrial Magnetism of the Carnegie Institution of Washington, this Institution became actively interested in the measurement of ground-resistivities as a means of attacking certain problems related to earth-current phenomena. As a result, Messrs. Gish and Rooney of the Department developed an apparatus for the measurement of ground-resistivities. A number of studies were undertaken by various departments of mines in the United States and in Canada, in close cooperation with the Carnegie Institution of Washington, with the object of finding out to what extent the Gish-Rooney method could be used in the determination of sub-surface geologic structures. The results have been so encouraging that the literature dealing with the theory and geologic possibilities of the "Resistivity-method" has grown very rapidly since that time.

In view of the great stimulus which the magnetic and electrical methods of prospecting have received through Bauer's active interest, it appears to be a fitting tribute to this eminent geophysicist to describe a number of outstanding accomplishments which have been made in late years with the resistivity and magnetic methods.

The unexpected in adaptations of geophysics to geology

To a geophysicist engaged in the scientific development of geophysical prospecting-methods, the most fascinating experience is the unexpected adaptation of geophysical methods to certain geological problems which at first glance would not seem amenable at all to this type of prospecting. No wonder the enthusiastic geophysicist is often labeled as an optimist, but the experience of late years seems to prove that the question whether or not a geophysical method is applicable to a certain type of geologic problem can only be decided by an actual survey of the ground to be tested.

In fact, that is the manner in which many applications of geophysical methods have been worked out and not by reasoning and systematic planning beforehand. Of course, after the adaptability of geophysics to a certain type of geologic problem had been established, it was always easy to say afterwards why they had worked. On the other hand, experience has also often shown that a geophysical method may not work out, although from a consideration of rock-properties, structural condi-

tions, and surveys made under similar geologic conditions, it would seem that it had the best chance of success. This bears out what was said before, namely, that the final decision as to whether geophysics is applicable to a certain type of geologic problem can only be obtained from an actual survey. It also bears out the extreme importance of a knowledge of the geologic conditions, that is, a consideration of such geologic factors which are of geophysical significance, both in regard to the sought as well as the interfering features.

Possibilities and limitations of "indirect" prospecting

Not so long ago when magnetic prospecting was used only as a means of finding iron-ore, nobody, not even the greatest optimist, could have ventured to predict that magnetic prospecting could be applied in locating oil-structures, placer gold, bauxite, copper, etc. The number of commercial geologic problems which can be attacked by geophysics are ever increasing. Usually some sort of an association of the commercial mineral with a geophysically effective part of the structure is utilized; the relationship between effective formations and associated minerals is seldom determinable beforehand and has to be worked out by an actual survey for each case separately.

For instance: In one area a productive oil-structure may appear (through association with a granite ridge) as a magnetic high; yet, the same type of magnetic high in an adjoining area, with formations of the same geologic age covering the ridge, may not be productive because the formations may have changed in lithologic character from one area to the other. Or, taking another example of the application of geophysics in mining: a placer-gold channel in one area may be found to be associated with a magnetic anomaly; however, a similar anomaly in another area of the same general geologic structure would not mean that the black sands in the channels there are associated with gold.

In other words, these "indirect" applications of geophysics to the location of minerals not only hold the possibility of considerable successes, but at the same time the danger of tremendous failures if the interpreting geologist-geophysicist commits an error in evaluating the results.

The space allotted to this paper does not permit of covering fully all possible geologic applications of the magnetic and the resistivity-methods. Only a few hitherto unpublished examples have been selected with the object of demonstrating the great possibilities of these methods under favorable geologic circumstances. Partly, the selection has been so made as to show unusual adaptations of geophysics to geologic problems which offhand would not appear suitable while in the other examples the principle was known, but the survey was selected because of an unusually good agreement between geology and geophysical results.

A demonstration of the possibilities of the magnetic method

(*a*) *Magnetic prospecting for gold placers*.—While there are a number of cases known where the magnetic method has been used to locate the enrichment channels in placer-gold deposits, no instance has been published as yet where gold could be located *in situ* by means of the magnetometer; such a case will be cited below.

The magnetic anomalies due to black sands in placer channels are

fairly large, and, depending on the depth to bedrock, run at times up to 200-300 γ ($1\gamma = 0.00001$ c.g.s.) Hence, if the association of gold with the black sands has been established in a given locality, the anomalies can be traced readily, even with crude instruments. Magnetic studies of placer-gold deposits have been described by Gibson, Laylander, and Heiland.[1] The method has found commercial application in Alaska and British Columbia. Under favorable conditions, that is, when the heavy concentrates occur in nearly the same proportion everywhere in a channel, the magnetic values run exactly proportional to the gold values of the ground.

On the other hand, it is always necessary to exercise extreme care in the interpretation of the results, particularly when transferring the results obtained in one area to another, for a strong magnetic anomaly may not at all be indicative of a large gold value. There are river channels accompanied by large magnetic anomalies which do not carry gold at all or carry ("flake") gold in such a manner that recovery at a profit is difficult or impossible.

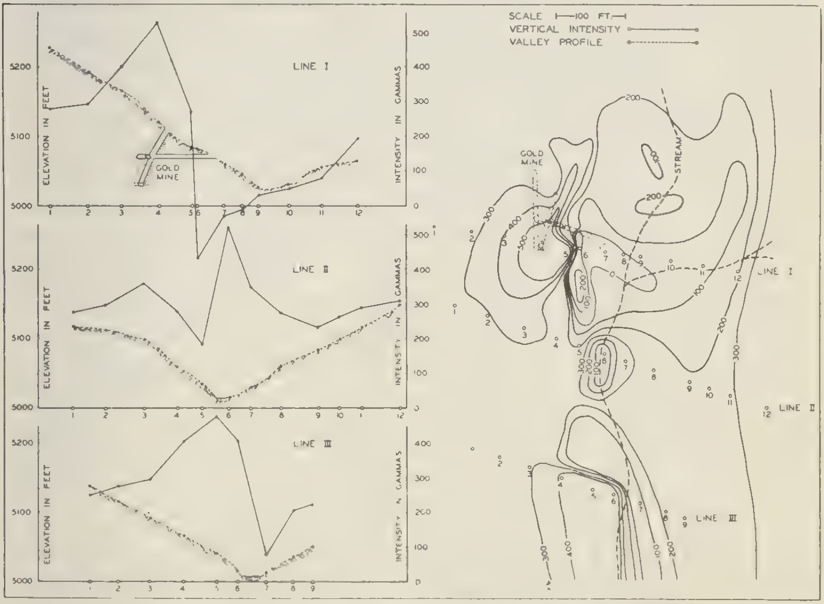


FIG. 1—Vertical-intensity isanomalics and profiles across a gold-ore deposit

(*b*) *Magnetic prospecting for gold in place* It is rather surprising that magnetic prospecting has not, to the author's knowledge, been applied to the location of gold in place; for, while in a placer the magnetite and the gold *may* have been derived from different rocks, one could conceive of such geologic conditions that both gold and magnetite would come from one and the same rock.

[1]For references to the literature, see C. A. Heiland and Dart Wantland, A selected list of books and references on geophysical prospecting, Colorado School of Mines Quarterly **26** (3), July 1931.

If the latter is the case, and if the rock carrying both gold and magnetite can be differentiated magnetically from the country rock or other *magnetic* formations *with no value*, the application of the magnetometer can yield very good results. This is well demonstrated by the data shown on Figure 1, which were obtained by B. O. Winkler. Gold is found in this area in black shales; they run from very little to $25 and more per ton in value. The shales are metamorphosed and magnetite-banded; there is evidence of igneous activity in form of porphyry which is also magnetic. Beyond this, there is little known about the geology. The Figure shows the results obtained at some very old mine workings (traverse I) from which the ore is taken; operations were discontinued as the values were cut off an either side by faults. The limited extent of the zone of mineralization on the sides is well shown in the magnetic picture, as well as its dip. The negative magnetic anomalies are due to topographic effects (station below upper end of deposit). In the creek bed below the mine workings (traverses II and III) gold is taken from placers, the black sands of which are also magnetically effective. The assumption is that both the gold and the magnetite of these gravels are derived from the black shales nearby; judging from the magnitude of the anomalies and the fact that the gold nuggets found there are hardly worn it is possible that some of the creek workings are even on weathered ore in place.

(*c*) *Magnetic prospecting for oil-structures*—This application of the magnetic method is a striking example for both the possibilities of success as well as the dangers of indiscriminate interpretation when using a

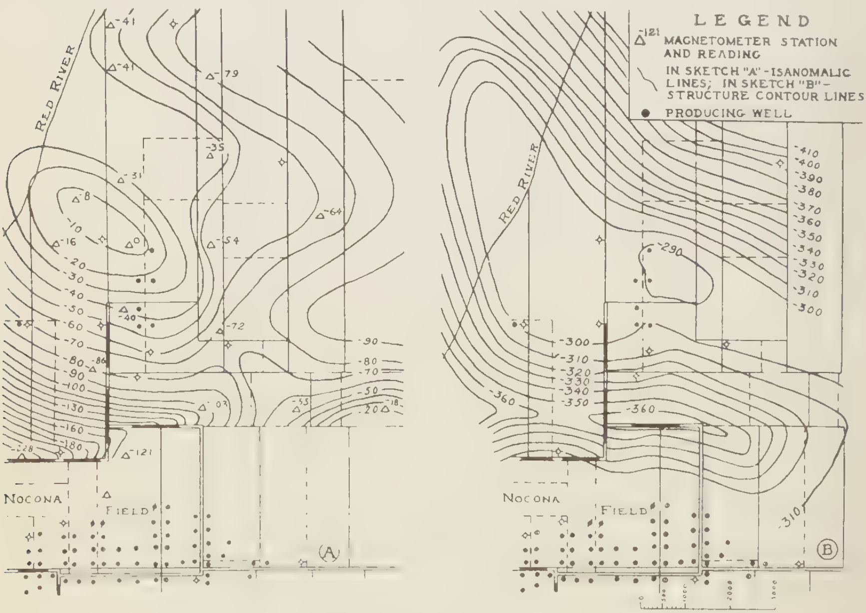


FIG. 2—Vertical-intensity isanomalics and structural contours in the Nocona Oil-Field

geophysical method to measure effects of formations which are associated with the sought ineffective structures or deposits. It is in prospecting for oil that the magnetic method has found its most widespread application, the principle being that oil-anticlines are often associated with uplifts of the magnetic crystalline basement.

This principle implies for an unambiguous interpretation a vertical and lateral consistency in the magnetization of the basement-rock; however, sometimes unexpected deviations from this condition occur which, when not realized by the interpreter, doom the method to failure. Furthermore, an uplift of the basement does not always mean an uplift of the overlying sediments. And finally, if the sediments are formed above a basement-fold or ridge, it does not necessarily mean that they contain oil; hence, there is a long way from a magnetic anomaly to an oil-field, as so many geologic factors enter into the picture. Failure to take these into consideration has caused much adverse criticism against the method and has brought about its use on a more conservative scale, followed up by other geophysical methods (notably seismic) which give data on the structure in the sedimentaries and not the existence of basement-uplifts alone.

To quote an encouraging example of the possibilities of the magnetic method in oil-work, reference may be made to Figure 2 which illustrates the results of some very early magnetometer oil-work which was done in this country. Both the magnetic and structural contours are shown as obtained in the Nocona oil-field on the Nocona granite ridge. The agreement of the two sets of contours is remarkable. (The displacement of the two high points is explained by the mechanism of differential settling or lateral folding (or both) which places the structural high point near the surface at a location different from that of the high in the basement-surface.)

A demonstration of the possibilities of the resistivity-method

Due to the great differences which exist between the conductivities of most types of rocks and those of ore-bodies, the obvious field for this method, like for other methods of electrical prospecting, should have been the search for ore. In fact, a number of mining and geophysical consulting companies have employed the resistivity-method for this purpose.

However, this was not the actual course of development. The very first experiments conducted by Gish and Rooney under the auspices of the Carnegie Institution of Washington demonstrated its adaptability to depth-determinations of horizontal formation boundaries, such as exist between artificial fill and bedrock, or between alluvium, etc., and bedrock. Further tests were made on such objects in the Michigan Copper Country in cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution; these tests also established for the first time the possibility of the location of ground-water by resistivity-methods. Since then, the successes of the resistivity-method have been outstanding chiefly in the civil engineering field: For the determination of depth to bedrock, on dam and reservoir sites, and the determination of rock-conditions for tunnel and foundation projects. The systematic location of ground-water by resistivity-measurements is still in its early stage; the difficulties seem to lie chiefly in the variability of the electrical-

geological characteristics of the surface-layers as well as of the water itself and their recognition in the resistivity-depth curve. It is impossible to go into the details here; much fundamental work in this line has recently been done by Tattam[2] which makes it possible to now recognize at least the most common type or types of resistivity-curves due to ground-water and the correct interpretation in regard to the depth of the ground-water level (see p. 350).

As it is impossible to cover the whole field here a few hitherto unpublished demonstrative examples will be selected again to illustrate the possibilities of the resistivity-method in civil engineering work.

(*a*) *Resistivity-work on foundation problems*—Through the courtesy of L. H. Henderson of the Metropolitan Water District of Southern California, the writer is in a position to use some examples of the work which was done by Messrs. Henderson and V. Pentegoff on a large scale to determine the nature of the rock-foundation and depth to bedrock along the proposed course of an aqueduct.

The two types of resistivity-prospecting, (1) resistivity-mapping and (2) "vertical electrical drilling" were used. The former took place chiefly along traverses across faults or zones of similar character suspected of weakness, while the purpose of the latter was to determine depth to bedrock and depth to ground-water table.

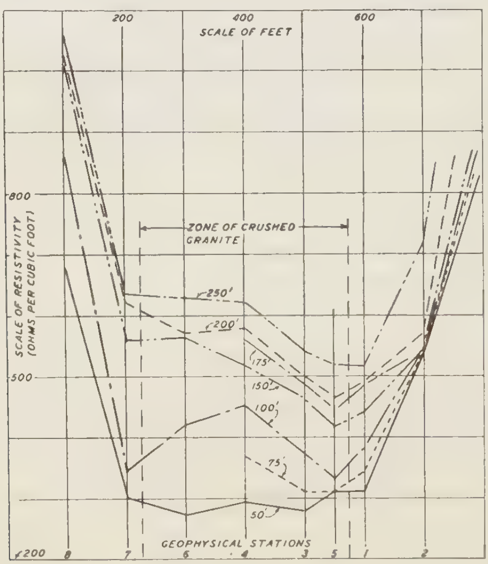


FIG. 3—Resistivity-traverses across a shattered zone (Courtesy L. H. Henderson, Metropolitan Water District of Southern California)

Figure 3 shows the apparent resistivities obtained on seven profile-lines across a fault-zone of crushed granite. It is seen that this zone stands out by its low resistivity-values (for the same reasons that recent geologic formations such as alluvium, diluvium, etc., have lower resis-

[2]C. M. Tattam, The application of the electrical resistivity-method of geophysical prospecting to problems of underground water. Doctor's Thesis, Golden, Colorado, 1932.

tivities than solid bedrock). The area to be rejected for foundation purposes can be outlined perfectly in the survey.

Figure 4 shows results of "vertical electrical drilling" in the same area to determine depth to bedrock. The four-terminal method was used, and the transition from coarse- to fine-grained material in the cover, as well as the change from overburden to bedrock, stands out perfectly in the curve. Such sharp breaks in the apparent resistivity-curve, particularly at the transition from cover to bedrock, have frequently been observed in practice, although they are quite contrary to the prediction of theory and model-experiments. Just what brings about, in some instances, a perfect agreement between theory and practice (with no sharp peaks or breaks at the boundaries, as in the case of the ideal ground-water curve, see Figure 5), while in other instances the indications of formation boundaries are better than those expected from the theory has not been determined as yet.[3]

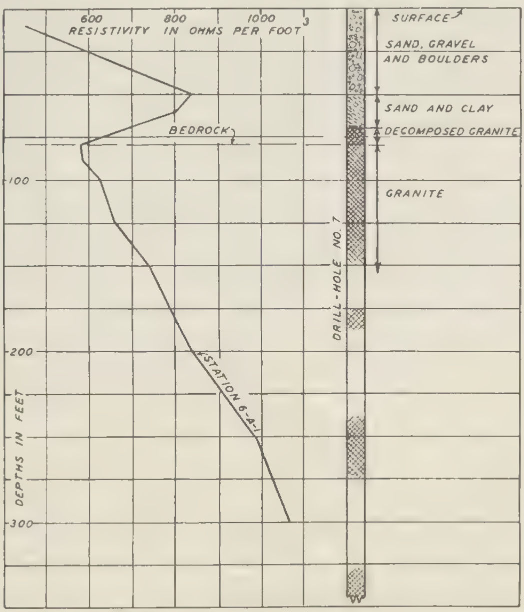


FIG. 4—Apparent resistivity-depth curve for bedrock depth-determination (Courtesy L. H. Henderson, Metropolitan Water District of Southern California)

(*b*) *Groundwater-resistivity work*—The resistivity-method has, finally, exceedingly good possibilities as a means of locating ground-water under favorable circumstances. The studies of the possibilities, limitations, and of the interpretative technique of this phase of resistivity-prospecting are only in the beginning stages. However, the work thus far done, both in the field and in the laboratory, permits of the statement that the majority of the ground-water indications conform to a type illustrated in Figure 5, the interpretation of which is not difficult. As seen from

[3]This holds for the four-terminal and related (single-probe) resistivity-methods. The indications obtained by the potential-drop-ratio methods are usually more distinct; formation boundaries are revealed by sharp peaks in the curves, according to both theory and practical experience.

Figure 5*d*, the ground-water layer is usually a good conductor, covered by a dry layer. Above these two there is a thin surface-stratum, the resistivities in which are subject to extreme variations as they depend on local meteorological factors. Often the very top surface-layer is dry and highly resistant, and the layer below is moist and conductive. Very often the indication for the very dry surface-layer is absent, such as shown by the results illustrated in Figure 5, *a* and *b*. Hence, we have the three-layer problem of the theory: Conductive layer at the surface, resistant layer in the middle, and conductive layer below; the curve corresponding to this theoretical case has been computed by Hummel and is reproduced in Figure 5*c*. The writer has had an opportunity to see quite

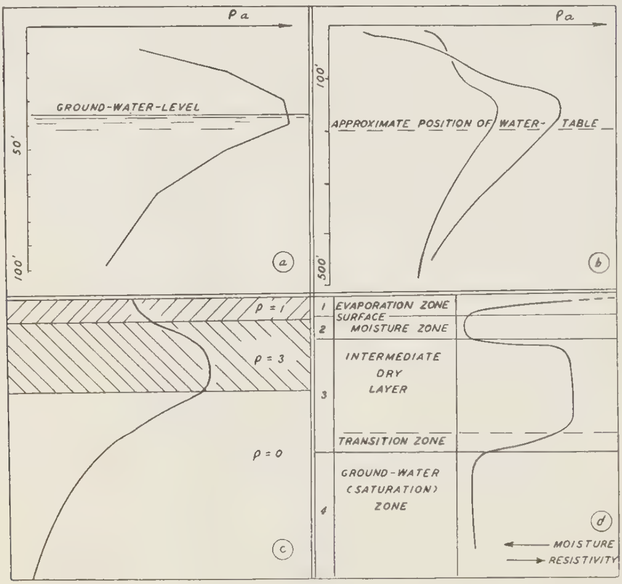


FIG. 5—Resistivity-depth curve in groundwater-determinations (actual and theoretical) —(*a*) resistivity-depth curve on Salt Marsh Well, California (courtesy Mr. L. H. Henderson); (*b*) resistivity-depth curve at Biggs Flying Field, Fort Bliss, Texas (after C. M. Tattam); (*c*) theoretical resistivity-depth curve (after J. N. Hummel); (*d*) resistivity-distribution in surface-layers

a few ground-water curves from different parts of the United States (Colorado, California, Michigan, New Mexico and Texas) and the great majority of them conform to this simple scheme. Two ground-water examples are shown in Figure 5, *a* and *b*. The recognition of the typical form of indication gives the possibility of working from there toward interpretation of the irregular and more difficult curves.

Unfortunately, the space available here does not permit us to go into further details of this interesting subject. The author hopes, however, that the reader has caught a glimpse of the many geological possibilities of the magnetic and resistivity methods, the number of which is continually increasing through the efforts of the pioneers in this line of work.

DEPARTMENT OF GEOPHYSICS, COLORADO SCHOOL OF MINES,
Golden, Colorado

ÉTUDES SUR L'ÉLECTRICITÉ ATMOSPHÉRIQUE AU VAL-JOYEUX ET À PARIS

PAR CH. MAURAIN

Des observations relatives à l'électricité atmosphérique ont été instituées au début de 1923 au Val-Joyeux, à 30 kilomètres S. W. de Paris, Observatoire dépendant de l'Institut de Physique du Globe de l'Université de Paris. Depuis le 1er mars 1923, le champ électrique est enregistré, et des mesures de la conductibilité électrique sont faites trois fois par jour, à 9h, 13h, et 17h. De plus, des mesures du nombre des gros ions et des petits ions ont été faites au même endroit au cours de plusieurs années. D'autre part, des mesures de la conductibilité et du nombre des ions ont été faites à diverses époques au Service central de l'Institut de Physique du Globe, qui est situé dans Paris, à l'angle des rues Saint Jacques et Pierre Curie, entre la Sorbonne et le Val-de-Grâce; ces mesures, faites avec des appareils semblables à ceux employés au Val-Joyeux, ont permis de comparer les résultats obtenus à la campagne et dans une grande ville.

La plupart des appareils ont été étudiés par E. Salles; ceux relatifs aux gros ions, par J. MacLaughlin. Les mesures au Val-Joyeux sont assurées par Gaston Gibault, assisté depuis un an par Michel Gibault. De nombreuses mesures d'ions au Val-Joyeux ont été faites par Garoux et Ravet. Des publications relatives aux observations et mesures au Val-Joyeux et à Paris ont été faites par MM. Salles, Gibault, MacLaughlin, Mme F. Bayard-Duclaux, Mlle Daude et moi-même. Ces publications se trouvent généralement dans les Annales de l'Institut de Physique du Globe ou dans les Comptes-Rendus de l'Académie des Sciences de Paris. Dans la présente note sont rassemblés quelques résultats généraux déduits de ces mesures.

Le champ électrique au Val-Joyeux est positif, c'est à dire dirigé vers le bas, pendant 89% du temps. Les moyennes mensuelles générales des valeurs horaires positives pour huit années d'observations sont les suivantes, en volts par mètre:

Janv.	Fevr.	Mars	Avril	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
133.7	129.4	105.3	89.7	81.9	83.7	89.4	91.2	85.2	87.1	108.0	132.6

La courbe *A* de la figure 1 représente la variation annuelle d'après les nombres précédents. La moyenne générale est 101.4.

La variation diurne du champ électrique a été étudiée dans un travail publié aux Annales, **7**, 121-129 (1929). Dans ce travail sont comparées les variations diurnes déduites des valeurs positives, des valeurs des journées régulières et de toutes les valeurs, qui sont d'ailleurs d'allures peu différentes.

Les moyennes mensuelles générales des valeurs de la conductibilité électrique totale $\lambda_+ + \lambda_-$ au Val-Joyeux (d'après les observations de 9h, 13h, et 17h) pour huit années sont, en unités E. S. $\times 10^{-4}$:

Janv.	Fevr.	Mars	Avril	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
0.97	0.96	1.14	1.39	1.48	1.40	1.52	1.66	1.46	1.32	1.11	0.89

La moyenne générale est 1.27×10^{-4}. Cette variation annuelle est représentée dans la courbe *B* de la Figure.

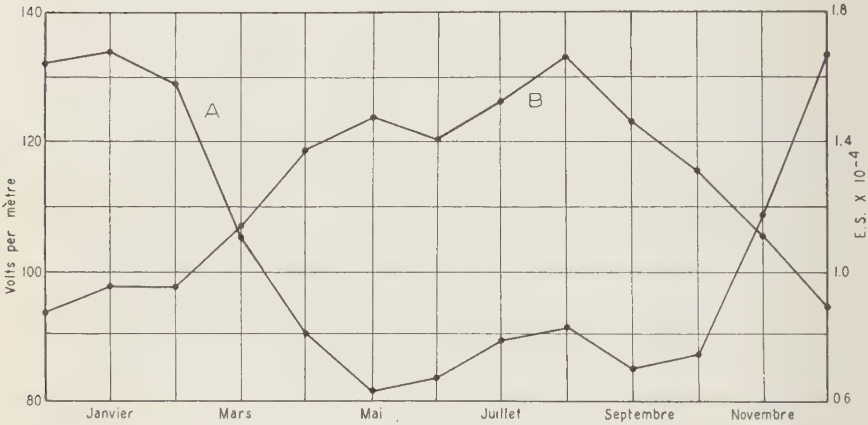


FIG. 1—Variation annuelle du champ électrique *A* et de la conductibilité électrique *B* au Val-Joyeux

Des valeurs du champ *F* et de la conductibilité $\lambda_+ + \lambda_-$ on peut déduire l'intensité du courant vertical $i = F(\lambda_+ + \lambda_-)$. Les moyennes mensuelles générales de l'intensité *i* (pour 6 années 1924-29) sont données dans le tableau suivant, en unités E. S. $\times 10^{-7}$. La première ligne du tableau est établie avec seulement les valeurs positives, c'est à dire correspondant à un courant vers le bas, et la deuxième ligne avec toutes les valeurs, c'est à dire que les moyennes sont des moyennes algébriques, correspondant à un flux résultant vers le bas.

Janv.	Fevr.	Mars	Avril	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
3.59	4.15	3.94	4.64	3.88	4.20	4.74	5.90	4.56	4.76	4.37	4.06
2.85	2.68	2.28	3.04	2.44	3.30	3.71	5.03	4.27	3.72	3.28	2.87

Ce courant vertical présente ainsi un maximum en été; des deux éléments qui interviennent dans son calcul, le champ électrique, maximum en hiver, et la conductibilité, maximum en été, c'est la conductibilité qui l'emporte.

Les moyennes générales des mesures du nombre des gros ions et des petits ions par cm³ à Paris et au Val-Joyeux sont les suivantes:

	Val-Joyeux	Paris
Nombre des petits ions positifs . . .	345	86
" " " " négatifs . .	283	70
Nombre des gros ions positifs	1620	16710
" " " " négatifs . . .	1610	16700

Ces nombres manifestent que dans l'atmosphère polluée des villes le nombre des gros ions est plus grand et celui des petits ions plus faible qu'à la campagne. Le dénombrement des particules en suspension donne lieu à une comparaison en accord avec l'hypothèse que ces particules

interviennent dans la formation de gros ions aux dépens des petits ions: ce dénombrement fait à l'aide d'un appareil d'Owens (jet dust-counter, avec grossissement 400) a donné comme moyenne des mesures faites au Val-Joyeux, en avril, 30, alors que la moyenne pour mars et mai à Paris est 670; on a constaté un parallélisme grossier entre la teneur en particules mesurée par l'appareil d'Owens et le nombre des gros ions, et les variations diurnes des deux quantités sont analogues.

Des mesures de la conductibilité électrique faites à Paris pendant huit mois ont montré qu'elle est environ 4 fois plus petite qu'au Val-Joyeux, ce qui concorde avec le rapport des nombres des petits ions $(345+283)/(86+70)=4$.

La conductibilité électrique étant due presque uniquement aux petits ions, la mobilité k des petits ions d'un certain signe peut être déduite de la formule $\lambda = n\, e\, k$, n étant le nombre d'ions par cm^3 et e la charge unitaire. On a trouvé ainsi, d'après les résultats obtenus simultanément au Val-Joyeux pour λ et n, 1.51 cm/sec pour la mobilité des petits ions positifs dans un champ d'un volt par cm, et 1.91 pour la mobilité des ions négatifs.

Les moyennes annuelles du champ électrique et de la conductibilité ne présentent pas une variation analogue à celle de l'activité solaire. Elles ne portent d'ailleurs pas sur une période assez longue pour que cette comparaison soit bien démonstrative.

Des statistiques faites d'après les observations du Val-Joyeux manifestent que, de manière générale, une visibilité relativement forte correspond à une conductibilité relativement forte et à un champ relativement faible. En particulier G. Gibault a montré que cette correspondance se présente dans les variations annuelles déduites des moyennes mensuelles. De telles études sont d'ailleurs délicates, parce que la visibilité dépend de facteurs complexes, dont il est difficile de tenir compte. Les résultats d'études statistiques peuvent se présenter de manières diverses. Par exemple, dans ces derniers temps ont été publiés les résultats de longues observations de la visibilité du Mont-Blanc (4810 mètres) vu, d'une part, du sommet du Puy-de-Dôme (1470 metres; distance 305 kilomètres; P. Chofardet), d'autre part de collines voisines de Besançon (610 mètres; distance 165 km; J. de Lagaye). Dans les deux cas, les jours pendant lesquels on voit le Mont Blanc sont très nettement le plus nombreux en hiver, c'est à dire à l'époque pour laquelle, au voisinage du sol, le champ électrique est le plus grand et la conductibilité le plus faible.

Institut de Physique du Globe,
Université de Paris,
Paris, France

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Ahrens, W. Ergebnisse magnetischer Untersuchungen im Vulkangebiet des Laacher Sees in der Eifel. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 4, 1932 (320-336).

American Geophysical Union. Transactions of the American Geophysical Union. Thirteenth annual meeting, April 28 and 29, 1932. Edited by J. A. Fleming, General Secretary. Washington, D. C., Nation. Res. Council, June, 1932 (401 with illus.). 25 cm. [For abstract of these Transactions, see this issue of the Journal.]

Alexanian, C. L. Traité pratique de prospection géophysique à l'usage des géologues et des ingénieurs des mines. Paris et Liége, Librairie Polytechnique Ch. Béranger, 1932 (268 avec 133 figs. et 2 pls. hors texte.). [Contains detailed treatment of magnetic and electric methods of underground prospecting.]

Angenheister, G. Magnetfeld der Erde. Handwörterbuch d. Naturw., 2. Aufl., Bd. 6, 1932 (652-680). [Verlag von Gustav Fischer in Jena.]

Burmeister, F. Erdmagnetische Vermessung der Rheinpfalz. Nebst einem Anhang: Geologische Deutungsversuche, von O. M. Reis. München, Veroff. Erdphys. Warte, Sternwarte, Heft 6, 1932 (51 mit 4 Karten). 29 cm.

Copenhagen, Det Danske Meteorologiske Institut. Magnetisk aarbog, 1ste del: Danmark (undtagen Grönland)—Annuaire magnétique, lère partie: le Danemark (excepté le Greenland). 1930. Köbenhavn, G. E. C. Gad, 1931 (32). 32 cm.

Dehalu, M., et M. Merken. Nouvelle carte magnétique de la Belgique. Bruxelles, Hayez, 1931 (125 avec 7 cartes). 29 cm. [Université de Liége, Institut d'Astronomie et de Géodésie, Physique du Globe, No. 1.]

Egypt, Physical Department. Meteorological report for the year 1926. Cairo, Ministry Pub. Works, Physical Dept., 1932 (xi+156). 32 cm. [Contains values of the magnetic elements at Helwan Observatory for 1926.]

Dyson, F. W. Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich. Read at the Annual Visitation of the Royal Observatory, 1932 June 4. Greenwich, Royal Observatory, May 24, 1932 (19). 31 cm. [This report covers the period May 11, 1931 to May 10, 1932, and contains an account of the magnetic work at Abinger Observatory during that time.]

Fleming, J. A. Magnetic investigations of the Carnegie Institution of Washington May 1931 to April 1932. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (148-152).

Frazer, C. Observing the Earth's magnetism. Tycos, Rochester, N. Y., v. 22, No. 3, 1932 (91-93).

Gjöa Expedition. The scientific results of the Norwegian Arctic Expedition in the Gjöa 1903-1906 under the conduct of Roald Amundsen. Part. I. Geofys. Pub., Oslo, v. 6, 1932 (248 with map and illus.). [This volume contains three reports: (1) Scientific work of the Expedition, by the Editorial Committee (N. Russeltvedt and A. Graarud). In this report the magnetic work which was undertaken chiefly to determine as far as possible the present geographical co-ordinates of a mean pole-point, is briefly discussed. (2) Astronomy, by H. Geelmuyden. (3) Meteorology, by A. Graarud. In this last report the auroral observations are included.]

Greenwich, Royal Observatory. Results of the magnetic and meteorological observations made at the Abinger magnetic station, Surrey, and the Royal Observatory, Greenwich, respectively, in the year 1930, under the direction of Sir Frank Dyson, Astronomer Royal. London, His Majesty's Stationery Office, 1932 (112 with 10 pls.). 30 cm.

Haalck, H. Ueber die physikalische Natur des magnetischen Rindenfeldes der Erde. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 3/4, 1932 (154-163).

ON POTENTIAL GRADIENT AND THE AIR-EARTH CURRENT

By F. J. W. Whipple

(1) *Introduction*.—The fundamental phenomena in the atmospheric electricity of fine weather are three. The gradient of potential is normally positive, that is, such that the electric force drives positive electricity downwards. The air is a conductor of electricity, the conductivity depending on ionization. Electricity flows continually into the ground, the current being positive as long as the potential gradient is positive.

Of these three phenomena the first two have been studied extensively but the third has received much less attention. There is even a lack of agreement as to the relation between gradient, conductivity, and current. The principal object of this little paper is to discuss this relation. Incidentally the apparatus used at Kew Observatory for the measurement of air-earth current is described and the theory of the variation of potential gradient with height is considered. The views which I express are not original. They are generally held, I believe, by the English school in atmospheric electricity.

(2) *The measurement of air-earth current*.—It is generally recognized that measurements of potential gradient should be made when possible over level ground in an open space and that measurements made under other conditions should be standardized by comparison with measurements made in the open. The aim in measurements of air-earth current should be similar, to estimate the current over level, open ground. In the long series of observations, which have been made at Kew Observatory since 1910, there has been an approximation to this ideal. Recently improvements have been made and it may be claimed that the ideal is almost reached.

The older method was to use a Wilson electrometer mounted on a tripod at a convenient height above the ground. The electrometer was surmounted by a small plate provided with a guard-ring and in addition to the current received by the plate, the average strength of the electric field above it was measured. The equipotential surfaces being distorted, the strength of the electric field over the plate was about five times the strength of the undisturbed field over the ground. By assuming that the current was proportional to the field-strength the current over the ground could be estimated.

To improve on such estimates it was necessary to provide a plate at ground-level and to arrange the observations in such a way that the flow of electricity would not be affected by the presence of the observer. For this purpose an underground laboratory has been constructed. On account of the risk of floods the roof of the laboratory could not be at the same level as the surrounding lawn but a large platform has been made and the flat surface of the platform is at exactly the same height as the roof. The plate used for the air-earth current measurements is accordingly surrounded by a level area about ten meters square.

The plate is 20 cm in diameter; immediately below the plate and inside the laboratory the electrometer is set up. The original Wilson apparatus has been modified by the substitution of a Lindemann electro-

meter for Wilson's gold-leaf instrument. Wilson's "compensator," a simple variable condenser, is retained. The object of the compensator is to allow the observer to keep the plate at zero potential while the air-earth current is being received. There is a cover which is mounted on an arm manipulated from below and can be put over the plate or swung out of the way and dropped into a recess in the platform.

For measurements of the strength of the Earth's field, that is, the potential gradient, the plate is exposed and earthed, then covered. The field-strength is proportional to the deflection of the electrometer. As the electrometer is dead-beat the observation takes only a few seconds. For measurements of the air-earth current the plate is exposed for a known time, generally five minutes. At the end of that period the charge on the plate is measured with the cover in position.

The conductivity of the air over the plate is estimated by comparing the current with the strength of the field. The conductivity found in this way is of course the conductivity for positive electricity. It is convenient to denote this by the symbol λ_1, the conductivity for negative electricity being λ_2.

Numerous experiments by Dr. Watson and Mr. Scrase have demonstrated that the field-strength over a plate flush with the ground is in close agreement with the average potential gradient for the first metre above the ground. Accordingly it can be stated that, under the conditions which prevail at Kew Observatory, the volume-charge of electricity is small. The charge in the first metre above the ground is too small to be revealed by such comparisons and is probably not more than one per cent of the charge on the ground. The sign of any such volume-charge is not known. Other experiments, made with artificial fields, have confirmed the hypothesis that the effective conductivity over the test-plate is λ_1, the conductivity for positive electricity.

These experimental results may be summed up in the formula

$$i = \lambda_1 F$$

in which i = the air-earth current, λ_1 = the conductivity for positive electricity, either at ground-level or at a convenient point at a height of about a metre, and F = the potential gradient either at ground-level or averaged over a metre.

On the other hand most investigators have said that the vertical current through the atmosphere must be carried by both positive and negative ions and have written down an equation equivalent to

$$i = (\lambda_1 + \lambda_2) F$$

Without staying to consider the reason, we may say dogmatically that this formula is wrong and that the people who have used it have over-estimated the air-earth current by an amount of the order 100 per cent. Thus where Kähler deduces[1] from the annual means of F and $\lambda_1 + \lambda_2$ the value 2.2×10^{-16} amp/cm^2 for the vertical current at Potsdam, we should reduce his estimate by multiplication by $\lambda_1/(\lambda_1 + \lambda_2)$ or 53/98 and say that the air-earth current at Potsdam was 1.2×10^{-16} amp/cm^2. Kähler says that, if the current over the whole Earth were the same as at Potsdam, the total flow from the atmosphere to the ground would be about 1000 amperes. This estimate should, it appears, be amended to 500 amperes.

[1]Einführung in die atmosphärische Elektrizität. Berlin, 1929, p. 179. The values of λ_1 and λ_2 are quoted from p. 37, namely, $\lambda_1 = 52 \times 10^{-6}$ and $\lambda_2 = 45 \times 10^{-6}$ in electrostatic units.

(3) *Conduction and Diffusion*—To reconcile the conflicting views of the air-earth current we must take account of the volume-charge of electricity and of the way in which this volume-charge is affected by diffusion. It is well known that, in problems of the free atmosphere, it is diffusion by eddies which is effective not merely diffusion by Brownian movements.

Let V be the potential at the height z so that the potential gradient is $\partial V/\partial z$. If the density of the space-charge is ρ then

$$\rho = -\frac{1}{4\pi A}\frac{\partial^2 V}{\partial z^2} \tag{1}$$

The constant A in this formula is unity when electrostatic units are adopted but, if V is measured in volts, ρ in coulombs per cubic centimetre, and z in centimetres, we must take for A the value 9×10^{11}.

If the coefficient of eddy-diffusion is κ then the rate at which electricity is brought down by diffusion is $\kappa \dfrac{\partial\rho}{\partial z}$ or $-\dfrac{\kappa}{4\pi A}\dfrac{\partial^3 V}{\partial z^3}$. Adding the conduction-current and the diffusion-current we find that the total current i is given by the equation,

$$i = (\lambda_1 + \lambda_2)\frac{\partial V}{\partial z} - \frac{\kappa}{4\pi A}\frac{\partial^3 V}{\partial z^3} \tag{2}$$

In reality λ_1 and λ_2 and also κ depend on the height, z. For the sake of mathematical simplicity let us regard these coefficients as constant. The current i is independent of height and accordingly

$$(\lambda_1 + \lambda_2)\frac{\partial^2 V}{\partial z^2} - \frac{\kappa}{4\pi A}\frac{\partial^4 V}{\partial z^4} = 0 \tag{3}$$

If a^2 be written for $\dfrac{\kappa}{4\pi A(\lambda_1+\lambda_2)}$ this equation takes the simple form

$$\frac{\partial^2 V}{\partial z^2} = a^2\frac{\partial^4 V}{\partial z^4} \tag{4}$$

The appropriate solution of this equation is

$$\frac{\partial^2 V}{\partial z^2} = -B\, e^{-z/a} \tag{5}$$

where B is constant.

It follows that

$$\frac{\partial V}{\partial z} = C + a\, B\, e^{-z/a} \tag{6}$$

where C is also constant. The constants B and C are to be evaluated so that the estimate of the current i at ground-level may be consistent with both of the equations

$$i = \lambda_1\left(\frac{\partial V}{\partial z}\right)_0 \tag{7}$$

and

$$i = (\lambda_1 + \lambda_2)\left(\frac{\partial V}{\partial z}\right)_0 - \frac{\kappa}{4\pi A}\left(\frac{\partial^3 V}{\partial z^3}\right)_0 \tag{8}$$

Solving these equations for B and C and substituting, we find that

$$\frac{\partial V}{\partial z} = \frac{i}{\lambda_1(\lambda_1+\lambda_2)} [\lambda_1 + \lambda_2 e^{-z/a}] \tag{9}$$

It will be seen that at a height great compared with a

$$\frac{\partial V}{\partial z} \rightarrow \frac{i}{\lambda_1 + \lambda_2} \tag{10}$$

To determine a we must adopt an estimate of the value of κ. The dimensional expression for κ is L^2/T, L denoting length and T time. Thus κ is proportional to the product of a velocity and a length; without attempting to set out a precise theory we note that the diffusion-coefficient must depend on the vertical velocities in the turbulent motion of the air and on the linear scale.

Since turbulence varies over a very large range it is to be expected that κ will be far from constant. L. F. Richardson has tabulated numerous estimates of eddy-coefficients. Of these the most suitable for our purpose is probably that derived by Schmidt from the records of temperature on the Eiffel Tower. The value for the whole year of the coefficient appropriate for potential temperature is given to a close enough approximation by the equation

$$\kappa = 10^4 \text{ cm}^2/\text{sec}$$

For $\lambda_1 + \lambda_2$ we may take a rough average of the values given by Kähler for Potsdam, $\lambda_1 + \lambda_2 = \frac{1}{10^4}$ E.S.U. $= \frac{1}{9 \times 10^{11}} \times \frac{1}{10^4}$ practical units, or say, $\lambda_1 + \lambda_2 = 10^{-16}$ ohm^{-1} cm^{-1}. Adopting these values for κ and $\lambda_1 + \lambda_2$ we calculate a from the formula

$$a^2 = \frac{\kappa}{4\pi A(\lambda_1 + \lambda_2)}$$

The result is $a = 3 \times 10^3$ cm $= 30$ meters.

If we neglect the difference between λ_1 and λ_2 the equation (9) may be written

$$\frac{\partial V}{\partial z} = \left(\frac{\partial V}{\partial z}\right)_0 \frac{1 + e^{-z/a}}{2} \tag{11}$$

It follows that the potential gradient at the height of 30 metres should be 68 per cent of that close to the ground; at 60 metres the gradient should be 57 per cent, and at 120 metres 51 per cent.

Another way of putting the same thing is to say that, whereas the total volume-charge in the whole atmosphere is exactly equal in magnitude and opposite in sign to the charge on the ground, 49 per cent of the volume-charge is in the lowest 120 metres. We are not concerned at present with the question where the other 51 per cent of the charge is located but it must be emphasized that our formulae are only applicable over the range of height in which the assumption that $\lambda_1 + \lambda_2$ is constant is a reasonable approximation. It is known that the conductivity of the air at great heights is very much larger than that near the ground, so that the exponential law of equation (9) will not hold for the upper atmosphere.

The accumulation of positive electricity in the atmosphere near the ground on account of the interplay of conduction and diffusion is known as the electrode-effect. According to our estimate this effect should be spread through a layer about 120 metres thick.

The question arises whether the electrode-effect should be appreciable within a metre or two from the ground.

By integrating equation (11) we find that

$$V = \left(\frac{\partial V}{\partial z}\right)_0 \frac{z + a\,(1 - e^{-z/a})}{2} \tag{12}$$

and for values of z small compared with a

$$V = \left(\frac{\partial V}{\partial z}\right)_0 \left(z - \frac{z^2}{4a}\right) \tag{13}$$

With $a = 30$ metres and a surface-gradient 100 volts per metre the potential at one metre should, according to this formula be 99 volts and the potential at two metres should be 197 volts.

Very much greater departures from the linear law of increase of potential with increase of height have been found by observation, notably by Daunderer and by Norinder. The analysis suggests that these departures are not to be regarded as manifestations of the electrode-effect. At Kew, to judge by observations of potential at one and two metres, the linear law is a very good approximation to the truth and the electrode-effect is certainly no greater than the figures which have just been given would indicate.

(4) *Conclusion*—The introduction of the assumptions of uniform turbulence and uniform conductivity has enabled us to develop a numerical theory. That theory helps us to understand how the effective conductivity at the surface of the ground may be λ_1 whilst the effective conductivity at a considerable height is $\lambda_1 + \lambda_2$. Moreover we have learned something about the vertical scale of the phenomena. We have found that the electrode-effect is likely to be appreciable up to a height of 100 metres. To consolidate our knowledge and get rid of the arbitrary assumptions we require measurements of the potential gradient and of conductivity in the lowest 100 metres. As far as I know no such measurements are available. Perhaps the kite which was used to good purpose in the early days of atmospheric electricity has still got work to do.

In conclusion let me urge that the vertical current is of such interest that it is well worth while to install apparatus for making direct measurements of the current free from uncertainties and assumptions. It is only by such measurements that our knowledge of the exchange of electricity between the Earth and the atmosphere can be consolidated.

Kew Observatory,
Richmond, Surrey, England

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism (Continued from page 354)

Hazard, D. L. Results of magnetic observations made by the United States Coast and Geodetic Survey in 1930. Washington, D. C., U. S. Dept. Comm., Coast Geod. Surv., Ser. No. 544, 1932, 33 pp. 23 cm.

Heathcote, N. H. de V. Christopher Columbus and the discovery of magnetic variation. Sci. Prog., London, v. 27, No. 105, 1932 (82-103 with illus.). [The author concludes that although Columbus was the first definitely to record an observation of the variation of the compass, the phenomenon was already known in Northern Europe at the time, though apparently not to Mediterranean navigators. The evidence considered shows that from the middle of the fifteenth until well into the sixteenth century, a variation of 11¼° E was accepted and allowance made for it by the compass-makers of Flanders and Germany.]

Hongkong, Royal Observatory. Report of the Director of the Royal Observatory, Hongkong, for the year 1931. Hongkong, Noronha and Co., 1932 (23). 25 cm.

Ingham, W. I. Magnetic convergence mapping. Mines Mag., Golden, Colo., v. 22, No. 7, 1932 (7-8).

Johnston, H. F. Optically-compensated variometers and wide-range recorders to be used during the Jubilee Polar Year. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (187-190).

Kato, Y., and S. Nakamura. Magnetic disturbances in the volcanic and seismic regions. Sendai, Saito Ho-on Kai (Saito Gratitude Foundation), Ann. Rep., No. 7, 1931 (270-271).

Magnetic distribution in the seismic area of the earthquake of November 26th, 1930. Sendai, Sci. Rep. Tôhoku Imp. Univ., v. 21, No. 1, 1932 (96-113).

Kennelly, A. E. Cosmic disturbances of the Earth's magnetic field and their influence upon radio communication. Sci. Mon., New York, N. Y., v. 35, No. 1, 1932 (42-46).

Keunecke, O. Der tiefere Untergrund des Subherzynen Beckens und seines nordwestlichen Vorlandes auf Grund magnetischer Messungen. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 4, 1932 (344-373).

Koenigsberger, J. Variometrisch bestimmtes magnetisches Profil Offenburg-Chiasso; Folgerungen über säkulare Aenderungen: Einfluss von Gesteinssuszeptibilität und Tektonik. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 4, 1932 (374-400).

Koulomzine, Th., und A. Boesch. Abhandlung über die von den Askania-Werken erbaute Vertikal-Feldwaage von Schmidt. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 3/4, 1932 (166-180).

Lugeon, J. L'Institut National Météorolcgique de Pologne. Organisation du bureau central météorologique, observatoire Aérologique, observatoire maritime, station magnétique. Varsovie, Drukarnia Państwowego Inst. Met., 1932 (222 avec figs. et cartes). 24 cm. [Pp. 185-192 contain a brief description of the Hel Magnetic Observatory and the Section of Terrestrial Magnetism.]

Mauritius, Royal Alfred Observatory. Results of magnetical and meteorological observations for the months of January to June 1931 (new series, v. 17, pts. 1-6). Port Louis, Govt. Press, 1931 (iv+107). 34 cm.

Muramoto, A. Weekly magnetic observations at Zinsen, Taihoku, Otomari and Palau during 1931. Hydrogr. Bull., Tokyo, 11th year, No. 6, 1932 (231-235). [Text in Japanese language.]

Nicholson, S. B. Researches at Mount Wilson Observatory of the Carnegie Institution of Washington relating to terrestrial magnetism. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (153). [Brief note referring to the continuation of routine observations.]

OBSERVED AIR-EARTH CURRENT AND MAINTENANCE OF EARTH'S CHARGE

By O. H. Gish

From an examination of the electrograms obtained at Washington, D. C., Tucson, Arizona, Watheroo, Western Australia, and Huancayo, Peru, it is found that, while with many of the moderate changes in air-potentials there are no corresponding changes in the air-conductivity, which undergoes much change within rather restricted limits, yet cases where changes in the air-conductivity of both signs are in inverse relation to simultaneous changes in the air-potentials are abundant.

In these cases the changes in air-potential are doubtless dependent upon those in air-conductivity. Although the converse, a dependence of air-conductivity upon air-potential may be expected, yet it does not seem to occur to the extent that theoretical deductions of Schweidler, Behacker, and Swann indicate. On the basis of those deductions, it was thought that on account of the nature of the exposure of the tubes through which air is aspirated from the outside in the conductivity-measurements, the "electrode-effect" would be greater than the theory implies. However, from this preliminary examination it appears that conductivity-changes which are dependent upon the electric field generally become conspicuous only when the electric intensity reaches about ± 300 volts or more per meter, although some exceptions have been noted. When these large intensities are of the normal sign (that is, positive potential gradient), then the negative conductivity drops abruptly to approximately zero-value, whereas the positive conductivity remains quite unchanged. The positive conductivity suffers a similar abrupt drop when the intensity is of opposite sign, whereas the negative conductivity in this case shows no perceptible change. The registrations of air-potential at such times are, however, not suitable for quantitative study. These should be registered with a less sensitive recorder and a more active collector in order that results such as described above may be more satisfactorily compared with theory. However the data as they stand, seem to justify some qualitative conclusions

These effects are much more abundant at Tucson than at any of the other observatories. During 1931 there were 97 days of complete record on which the conductivity of one or the other sign vanished for one-tenth hour or more, the positive registered approximately zero during a total of 101.2 hours, and the negative during 46.8 hours (omitting three days on which the record of one sign was incomplete). On May 15, from $16^h.4$ to $18^h.0$, the positive conductivity was continuously at this low value. The air-potential during this interval was of negative sign and the negative conductivity did not differ appreciably from the normal value. However, shortly after 18^h the air-potential reversed sign, the positive conductivity returned to normal while the negative conductivity practically vanished for about 0.3 hour.

That the conductivity of one sign should be wiped out by an intense field is, of course, to be expected. It is the manner and extent of such occurrences that seem of interest. Of especial importance is the

fact that the time during which the positive has vanished is about twice that for the negative. It is obvious that this circumstance should be taken into account when considering the problem of the maintenance of the Earth's charge. This comparison, of course, also implies that values of negative potential-gradient, in excess of a certain value, are about twice as abundant as are corresponding values of positive gradient. Then with the negative conductivity practically unaltered and for the conditions found at Tucson in 1931, simple calculation shows that the loss of negative charge from the Earth would be compensated during thunder-storms if at these times the gradients are about 100 times the normal value. Although gradients of this magnitude do occur, there are at present not enough data for a further quantitative test of this suggestion.

Although it seems likely that silent discharge, due to ionization by collision, from such objects as blades of grass, may act in maintaining the Earth's charge, yet one finds in examining these records only occasional indications that ionization by collision occurs in the atmosphere at times of thunder-storms. Large unsteady impulses of only a few minutes' duration sometimes follow one upon another, apparently simultaneously in the registrations of both positive and negative conductivity. In some cases this continues for a half-hour or more. At these times the spot of the air-potential recorder is always off scale. Although registrations of this character are so rare, even at Tucson, that some years of record, and no doubt special recording-equipment, will be required to definitely determine their nature and origin, nevertheless it seems safe to say that silent discharges in the atmosphere are generally of small importance in comparison with other processes which transport electricity between the Earth and the atmosphere.

A more detailed study of the several relationships between changes in air-conductivity and in air-potentials can be made with the data at hand, and would, it is believed, reveal additional features of interest. It is hoped this may be done and a more complete report made soon.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

THE SIGNIFICANCE AND ACCURACY OF MEASUREMENTS OF EARTH-CURRENT POTENTIALS[1]

By W. J. Rooney

Abstract—The superficial simplicity of measurements of earth-current potentials makes them liable to error due to inadequate appreciation of the requirements for securing satisfactory records and has led to faulty interpretation of the results obtained. Records from the multiple systems at Watheroo and Huancayo demonstrate the lack of signifigance of the absolute values of potential recorded and of the long-period changes in them, most of which are due to meteorological conditions. The value of independent records as a check on the satisfactory operation of the recording equipment and as an indication of anomalous results due to local structural inhomogeneity is shown by examples taken from the records from these two observatories. Duplicate potential records and earth-resistivity data both are essential for adequate study of the phenomenon.

In some respects there is no geophysical measurement as easily made as that of earth-current potential. All one has to do is to take a galvanometer or millivoltmeter and connect its terminals to two points on the Earth. The distance between the two points may be almost anything, depending, of course, on the sensitivity of the particular instrument chosen. When this is done, one will get deflections or readings which have all the earmarks of being due to earth-current flow. At least they will in all probability indicate potentials which will vary with time of day and with season of the year and will be more or less consistent and recurrent for long intervals of time. Given two such instruments connected between two pairs of points which lie on lines of different orientation, the direction and the magnitude of the existing potentials can both be determined and the measurement is complete.

When this proceedure and apparatus are compared with those required for other geophysical measurements, such as those of the Earth's magnetic field or of the atmospheric-electric elements, they are almost absurdly simple. Consequently measurements of this type have been made from the earliest days of electrical science.

Why is it, then, that to-day we know so little about earth-currents and their relationships to the Earth's magnetic field? The answer to this question is two-fold. First, the simplicity of the measurement is more apparent than real. While it is true that potential records can be obtained almost anywhere, anytime, and easily, a careful examination of the records will show that the effect for which we are looking is masked in these potential records by a number of extraneous effects present because of chemical and physical conditions at the electrodes used to make contact with the ground. With the average short line installation—by short lines is meant anything from one to ten kilometers or so—these contact-potentials may range from five to fifty times as great as the potentials due to earth-current flow, and they will vary widely and quite independently of the earth-currents because of changes in the temperature of the electrodes or in the moisture- and salt-concentration in the surrounding soil. Even when the utmost precautions are taken to keep the electrode-environment as constant as possible large changes in contact-potential will occur during the course of a year, and, when such precautions are not taken, they may undergo, in addition to the long-period changes, a diurnal variation quite as great as, or greater

[1]This contribution bears on a subject in which Bauer was much interested and one to which, largely as the result of his initiative, the Carnegie Institution of Washington is contributing much observational material from the observatories of its Department of Terrestrial Magnetism at Watheroo in Western Australia and at Huancayo in Peru and in its cooperative work at Tucson in Arizona.—*Ed.*

than that of, the earth-current potentials themselves and so be readily confused with them.

The second reason for the slow progress in the understanding of earth-current phenomena is that the importance of allowing for or eliminating these extraneous effects was not sufficiently appreciated in the earlier investigations. Far too much weight, for instance, was given to the absolute values recorded and to the long-period changes in these absolute values, most of which represent simply electrode-effects. Moreover, little or no attempt was made to check the records of diurnal variation in such a way as to insure that the more rapid variations in contact-potentials were not contributing to the results obtained. Since electrode-effects are more closely connected to meteorological conditions than they are to the factors which affect earth-currents, this neglect led to conclusions which were often erroneous and not infrequently contradictory. As a result many investigators gained the impression that earth-current records are more or less meaningless.

When the measurement of earth-current potentials was undertaken at the magnetic observatories of the Department of Terrestrial Magnetism at Watheroo and Huancayo, provision was made to study electrode-effects and make possible the elimination of errors due to them by obtaining two or more independent records of each component of earth-potential through the use of different lengths of line, different electrodes with the same lengths of line, and even different types of connecting circuits. In the analysis of the data obtained only those features, or those portions of the recorded potentials, which are common to the independent records are attributed to earth-current flow, the remainder providing material for the study of electrode-performance.

The entire lack of significance of the absolute values recorded is at once apparent from a comparison of such independent records. For instance, during March, 1926, the potentials between the common electrode O at Watheroo[2] and electrode P', situated one mile north of it, was -28 millivolts, and that between O and P'', another electrode less than sixty feet from P', was $+41$ millivolts. If these potentials are interpreted as indicating current-flow between the two points, the first would show a considerable current flowing from P toward O, and the second an even larger current flowing from O toward P. This, of course, is manifestly absurd. However, in spite of the great difference between the conditions then existing at the two P-electrodes, as indicated by the large contact-potentials, the curves of diurnal variation obtained at the same time from the two sets of records were in very good agreement as to direction as well as amplitude, although the total range of diurnal variation at the time was only about two millivolts for the one-mile distance.

This is of course an extreme case for electrodes so close together, but even when electrodes are installed in such a way as to be as similar as possible contact-potentials as great as these and as misleading when considered separately are apt to be encountered between any two pairs of points selected for the measurements.

Further evidence that the absolute values of potential do not represent earth-current flow and that the changes they undergo are primarily due to changes in the conditions at the electrodes is found in Figure 1.

[2] O. H. Gish, Terr. Mag., **28**, 89-108 (1923).

Here the daily mean potentials recorded during the two-year period, 1929-30, are shown for the four lines recording at Watheroo during that time. Climatically the year at Watheroo is divided into two rather sharply defined seasons, wet and dry, light rains falling frequently from June to November while practically no precipitation, except that from infrequent thunder-storms, occurs during the remainder of the year. It is at once apparent from Figure 1 that the major changes in the mean potentials are associated with the transition from the one season to the other. In other words they are due to changes in the moisture-content of the soil or to the movement of the salt-solutions in it.

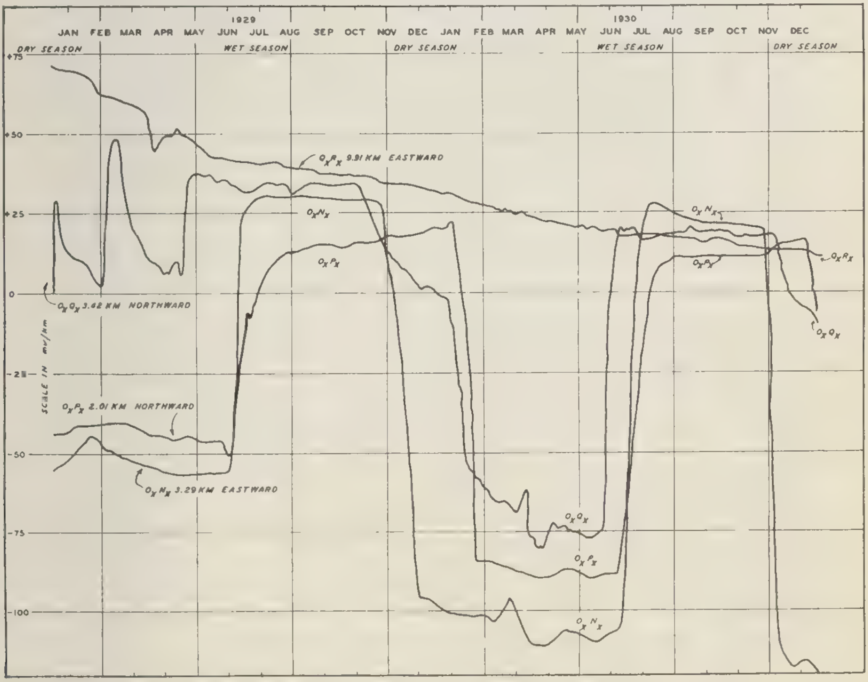


Fig. 1—Mean daily potentials earth-current lines Watheroo 1929-30

The surface soil in the region about the Watheroo Observatory[3] varies from loose sand which in some places appears to be almost pure quartz to a compact clay containing considerable quantities of magnesium salts. The clay also forms a thick hard-pan underlying much of the sandy area at no great depth. Naturally these two materials are quite unlike electrically and the difference becomes more marked during the dry season when practically all the moisture disappears from the sand while the clay apparently changes but little in moisture-content or electrical resistivity. The common electrode O_X is located well into the hard-pan and R is located in a low-lying area referred to locally as the

[3]W. J. Rooney and O. H. Gish, Terr. Mag., 32, 49-63 (1927).

"salt-branch" and into which there is sufficient drainage to keep the soil fairly moist throughout the year. Electrodes P_X, Q_X, and N_X are less favorably situated although none of them are set in purely sandy soil. It is for this reason that the contact potentials recorded between O_X and R show by far the least variation with season as is readily seen in Figure 1.

At Huancayo the surface soil is much more nearly homogeneous and the seasonal changes in its moisture are not nearly so marked[4]. Consequently the contact-potentials at the several pairs of electrodes there is less and the mean potentials recorded tend to be smaller in magnitude and far less subject to abrupt changes such as occur at Watheroo. In contrast to the Watheroo records where potentials greater than 100 millivolts are not uncommon and the yearly range in the potential between a given electrode-pair may run as high as 150 millivolts, the Huancayo records show mean potentials between the seven pairs used which lie mostly between 0 and 30 millivolts with a yearly range of not more than 5 to 10 millivolts. These smaller changes are, however, again found to be quite definitely connected with meteorological conditions. In no single instance has there been found any change in the mean potentials recorded at either observatory which can be attributed to the effect of magnetic or earth-current storms, the general trend of the daily means persisting through calm and disturbed periods alike.

It will generally be found, then, that the mean potentials recorded between any pair of electrodes are quite independent of their distance apart and that they afford but little direct information as to the magnitude or direction of the earth-current flow between them. Since the potentials representing earth-current flow are proportional to the distance between electrodes the ratio of the diurnal range to the mean values recorded will increase as the length of line increases. At Tucson[5] where the lines are 57 and 94 kilometers long respectively the mean potentials recorded are not more than 10 to 20 per cent of the daily range. At Huancayo the mean potentials are found to be less than the daily range when a length of line of more than five kilometers is used. Both positive and negative values, for instance, were found in all the daily records from line $3W$-$1E$ which had a length of about 6.75 kilometers. At Watheroo on the other hand the daily range is often only a few per cent of the mean potentials recorded.

At first glance this would seem to point to the desirability of using the longest lines obtainable, especially since somewhat less sensitive recording-apparatus can then be used. Despite the advantage held by the long lines in these two respects the use of short lines with more sensitive instruments is to be preferred once the irrelevance of the absolute values recorded is established. Duplicate independent records are seldom feasable when long lines are used and the cost of installation and maintenance is enormously greater. Where, as is usually the case in long-line systems, the existing lines of telephone or telegraph companies are used for reasons of economy, the choice of electrode-sites, direction of lines, and the type of line construction is severely limited, and satisfactory tests of line insulation and electrode-performance are difficult or even impossible. With short lines, on the other hand, the cost of a duplicate system is not at all prohibitive, the entire installation can be

[4] W. J. Rooney and O. H. Gish, Terr. Mag., **35**, 61-71 (1930).

[5] Carnegie Inst., Year Book, No. 30, 347 (1930-31).

laid out and maintained exclusively for the work at hand, and inspection and adjustments can be made conveniently, with the result that the conditions requisite for satisfactory recording can be much more readily secured.

One general conclusion reached from examination of the absolute potentials as shown in the duplicate records is that the measurements give no evidence of the existence of an unchanging component or "constant part" in earth-currents. In other words earth-currents are strictly alternating-currents although of relatively long periods of alternation.

Consequently all our knowledge of the phenomenon has to be obtained from a study of the short-period changes in the recorded values such as occur during disturbances or those found in the usual diurnal variation. We are interested in the absolute values, daily means, etc., only to the extent of insuring that they do not run riot and introduce errors in the determination of the former by taking on rapid variations of such period as to be confused with them. So far most of the study has been restricted to the diurnal variation, partly because the intermittent type of record given by the recording potentiometers at Watheroo and Huancayo is not too well adapted to the study of storms and partly because the diurnal variation is more readily treated statistically. This restriction to the study of variations is a handicap in some respects. As an indication of the activity of earth-currents, for instance, we can use the range of the diurnal variation or some sort of an integration of the variations with time but cannot employ any such alternative measure as the "interdiurnal variability" used in magnetic studies. The reliability and consistency of the diurnal-variation records are therefore of the utmost importance in the investigation of earth-current phenomena.

It is in this connection that the independent records secured from the multiple systems at Watheroo and Huancayo have proven of the greatest value since they afford a ready means of checking the accuracy and reality of the recorded variations and of determining probable sources of error. With them available it has been found possible to fix definitely the cause of unsatisfactory records in a number of cases and to obtain more satisfactory results by correcting defects in insulation or electrode-construction or by relocating electrodes so as to place them in more suitable environments or in locations where the structural conditions of the intervening portions of earth-current path is more advantageous.

The more general features of the diurnal-variation records from the two Observatories, as determined from the average or best representative records obtained, have been described in two previous papers[6, 7]. Because of the increasing interest in earth-current phenomena and the consequent possibility that the experience gained from the use of the multiple systems may prove helpful in operations carried on elsewhere, it seems worth while to discuss in some detail certain facts brought out by comparison of the individual simultaneous records. The records from Watheroo are probably the more illuminating in this respect because the physical characteristics of that site are such that satisfactory earth-current measurements are peculiarly difficult there. The inhomogeneity of the surface soil and the high resistivity of large parts of

[6]O. H. Gish and W. J. Rooney, Terr. Mag., 33, 79-90 (1928).

[7]O. H. Gish and W. J. Rooney, Terr. Mag., 35, 213-224 (1930).

it[8] militate against good electrode-performance, while the low resistivity of the ground in general has the effect of reducing the potential gradients corresponding to given earth-current densities to very low values and hence demands high accuracy in the potential measurements. For the very reason that the site is a difficult one, however, probably no better laboratory could have been chosen for developing the technique of the measurements and for determining the requirements for satisfactory registration.

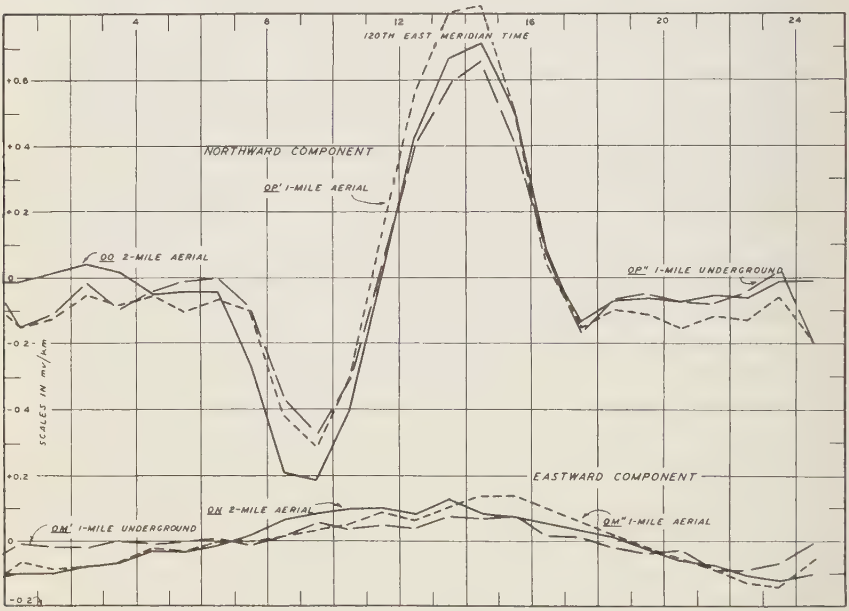


Fig. 2—Diurnal-variation earth-current potentials Watheroo August 1924 showing agreement individual records from original electrodes

With the original electrode-installation at Watheroo it was the practice to secure three simultaneous records of each component by determining the potential of an electrode at the common point O with reference to six other electrodes located as follows: Q, two miles due north of O; P' and P'', two electrodes close together, one mile due north of O; N, two miles due east of O; and M' and M'', close together one mile due east of O.

There are actually two electrodes at points O, Q, and N, as well as at M and P, but during most of the time the two were connected to the line in parallel and virtually formed a single electrode. Overhead lines ran to the electrodes two miles distant and both overhead and underground lines ran to those one mile distant. The overhead and underground connections were occasionally interchanged between the electrodes at the one-mile points to test the effect of the lines on the records. This portion of the comparison can be dismissed with the statement that no differences were apparent in the results obtained with overhead

[8]Cf. notes 3 and 6.

and underground lines except during thunder-storms, at which times typical disturbances are found in the records secured with overhead lines, those from the underground lines being entirely unaffected.

During the first four years of the system's operation, 1924-27, diurnal-variation curves were constructed for the northward component from the data recorded with the three electrode-combinations *OQ*, *OP′*, and *OP″*, for thirty-nine periods ranging in length from ten to thirty days. For eighteen of the thirty-nine periods the three independent curves so obtained showed an agreement that ranged from fair to very

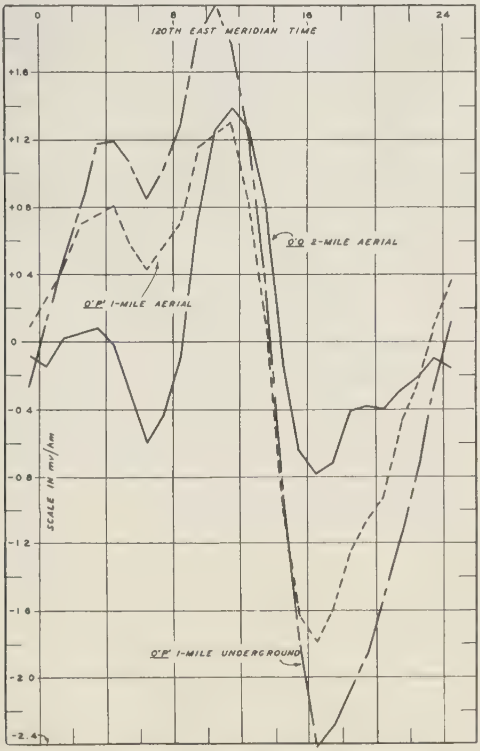


FIG. 3—Diurnal-variation northward earth-current component Watheroo last half January 1927

good. An example of what is termed good agreement is given in Figure 2, which shows the individual curves for the month of August 1924, curves for the eastward component being also shown in this case. During twelve additional periods two of the northward curves agreed closely and were similar in appearance to those in the first eighteen sets while one departed considerably from normal. For the remaining nine periods only a single one of the three combinations, namely *OQ*, yielded data from which a normal diurnal-variation curve could be constructed, the others showing various degrees of distortion. Figure 3 gives an extreme case of the lack of agreement, typical in character, which marked these nine periods. It shows the curves for the last half of January 1927.

This distortion of the diurnal-variation curve was found to be definitely associated with individual electrodes. When one of a pair at a given point, say P, was found to give a distorted record, the overhead and underground lines were interchanged at times without effect. This eliminated the possibility that faulty line-insulation might contribute to the trouble. It was also noted that the records were all quite generally satisfactory during the southern winter in which the rainfall at Watheroo is greatest and the diurnal temperature-range least. The abnormal records occurred almost exclusively in those months in which the soil was driest and the diurnal variation in temperature was large.

Referring again to Figure 3 the departures of the curves $O'P'$ and $O'P''$ from the solid curve $O'Q$ are seen to be quite regular as though a smooth curve of single period were superimposed on the more normal $O'Q$ curve. This is shown more clearly in Figure 4 in which the differences between the two distorted curves and the normal curve have been plotted. The resemblance of these residual curves and similar curves obtained at times for the eastward component to the daily thermograms was pointed out by O. H. Gish[9] who suggested a connection between the extraneous effects causing the distortion and the diurnal variation in temperature.

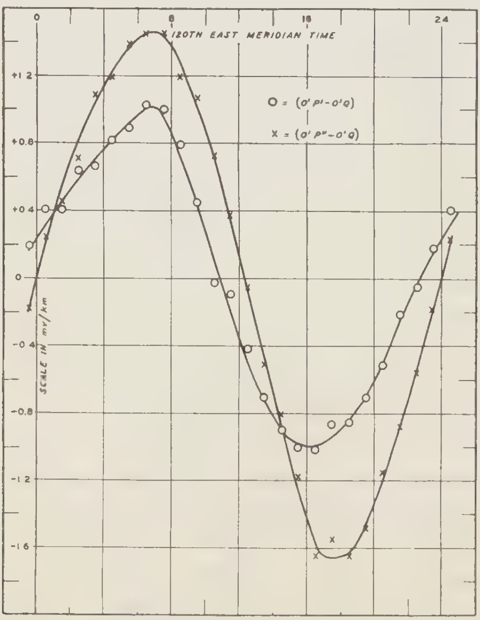


FIG. 4—Difference between distorted and normal diurnal-variation curves from Figure 3

The depth at which the electrodes were set, four to eight feet, was such that it was extremely unlikely that the electrode-surface proper could be affected appreciably by diurnal variations in temperature. An examination of the conductors leading from the electrodes to the lines showed distinct deterioration of their insulation. Any leak from

[9]Carnegie Inst., Year Book No. 24, 214-215 (1925).

these connecting leads to the ground will, of course, bring the copper conductor into play as a part of the electrode and be equivalent to having two contact-potentials in parallel through different resistances. The potentials recorded where such a condition exists is the resultant electromotive force of the combination and the error introduced into the measurement depends on the relative magnitudes of the contact-potentials and their associated resistances.

Under normal conditions this error might be expected to be small. However, the contact-potential of copper relative to lead, the material of the electrodes, or to the soil in which the electrodes were set, is large in proportion to the small variations of earth-current potential at Watheroo. Moreover the contact-resistance of some of the original electrodes which were set in very sandy soil became rather high during the dry season. For this reason the relative effect of the copper-ground portion of the compound electrode would tend to be enhanced at that time. It can be shown that, under the conditions then existing at point P, a very moderate insulation-leak from the connecting cable could produce the distortion shown in Figure 3 provided it undergoes a large diurnal variation.

It would appear at first glance that any error due to faulty insulation would be more in evidence during the rainy season than during the dry season. There can be no doubt that the insulation-leak persisted throughout the wet seasons and the fact that it did not appreciably affect the diurnal-variation records then also can be explained only on the grounds that, first, it must have undergone very little diurnal variation, and second, any effect it might tend to have in producing variations in the recorded potentials was minimized by the lowered contact-resistance of the electrode proper.

Replacement of the connecting leads by others with improved insulation resulted in immediate improvement in the records but the distortion reappeared after a time indicating that it was practically impossible to maintain a satisfactory relationship between the insulation of the connectors and the contact-resistances of the electrodes because of the high resistivity of the soil in which some of them were set. Accordingly an entirely new set of electrodes was installed during 1926, in locations selected so that their contact-resistances would tend to be low and fairly constant throughout the year. The distance between the electrode points on the south-north line was increased slightly, and the length of the west-east line was more than trebled to secure more accurate records of the small eastward component[10]. The new electrodes are designated by the same letters as the old ones but with the subscript x. The records obtained from them for four years or more were very satisfactory, the individual records agreeing well within the accuracy of the recording instruments. Figure 5 shows the curves obtained for both components during the last half of December, 1927. This is the time of year at which the conditions are least favorable to good recording but the difference between the individual records are quite insignificant. The extremely good records obtained for the very minute eastward component since the change in electrodes is particularly gratifying since completely satisfactory records for this component were never secured with the original electrodes.

Recently the records from one of the new electrodes, Qx, have shown

[10] *Cf* note 6.

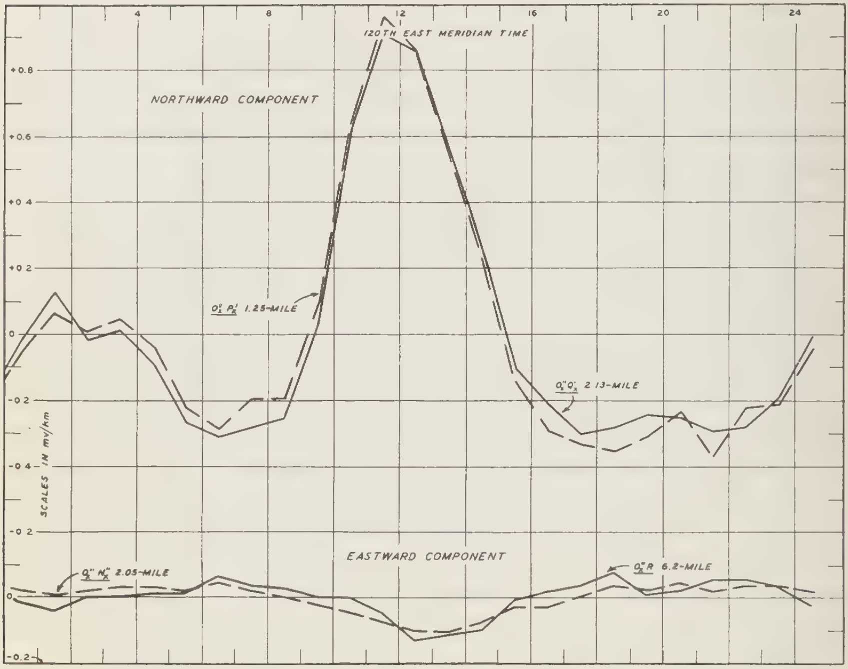


FIG. 5—Diurnal-variation earth-current potentials Watheroo during last half December 1927 showing agreement individual records from new electrodes

some evidence that extraneous effects similar to those which occurred at the old *P*-electrodes are creeping in again. *Qx* is the least favorably situated of the new electrodes and may possibly have to be relocated. It may be, on the other hand, that the connecting lead alone is at fault and that the salt-saturated subsoil at Watheroo is so destructive of insulation that a program of periodic replacement of the connecting leads to the electrodes will have to be adopted. At any rate the duplicate records make it possible to keep a constant check on the operation of the system and are a safeguard against unsuspected errors. Without them trustworthy data could hardly be secured at a site as difficult as Watheroo.

So much for the usefulness of duplicate records as a guarantee of the proper performance of the measuring system. Uncertainty or misapprehension as to the true significance of the recorded potentials may also arise at times from causes quite outside the measuring equipment. In this connection again the value of duplicate records can be shown. As a case in point let us consider the direction of the resultant earth-current vector at Huancayo, or, for simplicity, the magnitude of the eastward component there.

The layout of the earth-current lines at Huancayo and the principal topographical features of the immediate vicinity are shown in Figure 6. In order to provide the independent records the system is a dual one with two sets of electrodes each arranged in the form of a

cross. The set near the observatory site on Pampa Paccha is referred to as System 3, the other, located at a slightly lower level on the flat Pampa Sicaya, is designated as System 1. This arrangement was found best suited to the topography and has an advantage over the "right-angle common-point" layout used at Watheroo in that it gives no undue weight to effects associated with a single electrode, the common one.

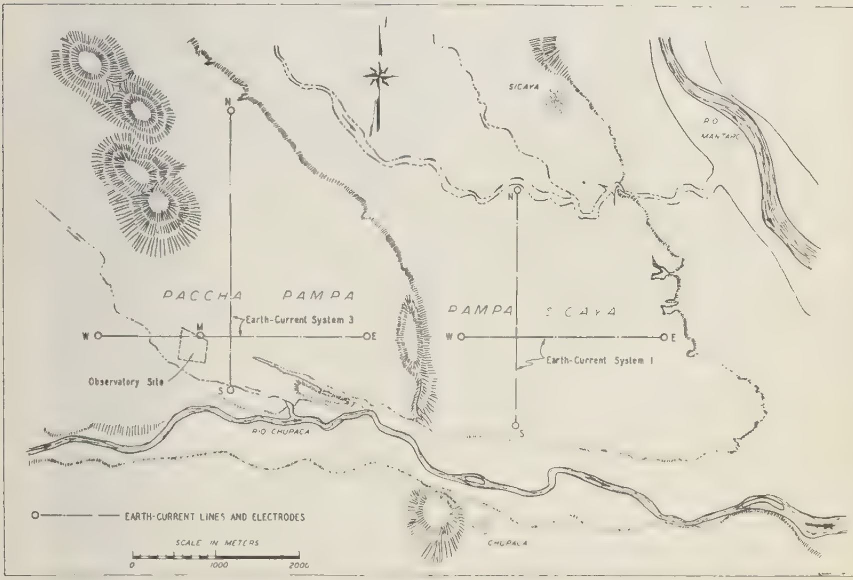


FIG. 6—Plan showing earth-current lines, Huancayo Magnetic Observatory

During the first twenty months of the system's operation simultaneous records of the eastward component were obtained from the electrode combinations *3W-3E*, *1W-1E* and *3W-1E*. The numbers here refer to the electrode-system and the letters to the respective electrodes. The diurnal-variation curves constructed from the three sets of data were found to be in very close agreement as to phase and general appearance but differed consistently in amplitude. The mean amplitude of the variation in gradient obtained from line *3W-3E* was always about 75 per cent greater than that obtained from *1W-1E*, while that recorded with the combination *3W-1E* was in every case almost the exact mean of those recorded on the other two lines. This last fact showed clearly that the difference between the System 3 and the System 1 records was not due to electrode-effects or other factors connected with the measuring apparatus.

At the end of this period a new electrode *3M* was installed and thereafter used in place of *3W*. This change was made primarily to reduce the amplitude of the variations in the recorded potentials by shortening the line and thus reduce loss of record due to off-scale deflections. As soon as recording with the combination *3M-3E* was begun, however,

it was found that the change had also eliminated the discrepancy in the amplitudes of variations in gradient as recorded on the two systems. This circumstance, together with the results of an earth-resistivity survey of the region[11], showed that the differences in the earlier records were due to a local area of high resistivity in the southwest portion of the region covered by System 3, the average resistivity there being about three times as great as that of the region generally. The effect of the higher resistivity is, of course, to increase the gradient corresponding to a given earth-current density.

This is a case where the results obtained from a single measurement might have been misleading through no fault of the equipment or method. Superficially the areas covered by the two systems are quite alike and, had only one been set up, it would, in all probability, have been System 3, since its location is more convenient to the Observatory. Conclusions drawn from the records of System 3 alone as to the magnitude of the eastward component and consequently as to the direction of the resultant earth-current vector would be considerably in error. Of course, the single record obtained from the system on Pampa Sicaya would have been sufficiently representative for the general locality in this case but, with it alone available, there could be no certainty as to its validity.

It goes without saying that this feature of the Huancayo records is just as strong an argument for securing complete earth-resistivity data in connection with earth-current measurements as it is for the use of multiple potential-recording systems. The desirability, in fact the necessity for resistivity measurements for adequate investigation of earth-currents has been emphasized so often elsewhere[12], however, that it is taken for granted in this discussion. For best results both resistivity-data and duplicate potential records appear to be essential.

To sum up, duplicate independent records of earth-current potentials (1) make it possible to differentiate between extraneous contact-potentials and the potentials arising from earth-current flow, and (2) afford a means of checking the performance of the recording apparatus and of detecting anomalous results due to the geological structure of the site. Where the independent records agree, this enhances the value of the records by increasing the probability that the features exhibited by the data are real and significant, a point of no small importance when the features in question are unusual in type or small in magnitude. Where they do not agree they, particularly when considered in conjunction with earth-resistivity data, almost invariably point the way for correcting faults in the recording apparatus or to explain anomalies due to structure.

The author wishes to acknowledge his indebtedness for the material used in this discussion to the efforts of O. H. Gish, chief of the Section of Experimental Work in Terrestrial Electricity, and of the staffs of the observatories at Watheroo and Huancayo. His thanks and appreciation also extend to J. A. Fleming, Acting Director, for continued support and encouragement of the work.

[11] *Cf* note 4.

[12] *Cf* notes 2, 3, 4, 6, and 7.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

HOW THE HORSESHOE-FORMED AURORAL CURTAINS CAN BE EXPLAINED BY THE CORPUSCULAR THEORY

By Carl Störmer

1. *The horseshoe-formed auroral curtains*—An important test of every theory of the polar aurora is that it gives a reasonable explanation of the characteristic arcs, bands, and curtains. This is possible by the corpuscular theory[1], developed by the late Professor Birkeland and myself many years ago, while no explanation is given by other theories. In particular, the ultraviolet theory of aurora set forth by Hulburt and Maris seems to me incapable of explaining those characteristic phenomena, where auroral rays are arranged along an arc or a band stretching across the sky many hundred kilometers long and everywhere very thin. Figures 1, 2, and 3 give a good idea of these remarkable forms[2].

With reference to those auroral curtains stretching across the heavens, I gave many years ago the following reasonable explanation. Under certain conditions bundles of electrons (or similar electrified corpuscles) may be spread out by the Earth's magnetism in the form of long,

[1]C. Störmer, Corpuscular theory of the Aurora Borealis, Terr. Mag., **22**, 23-34, 97-112 (1917); Twenty-five years' work on the polar aurora, Terr. Mag., **35**, 193-208 (1930).

[2]The figures are taken from the Photographic atlas of auroral forms and scheme for visual observations of the aurora, published by the International Union of Geodesy and Geophysics, Oslo (1930).

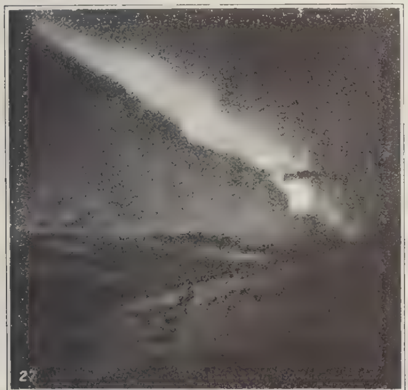


Fig. 1—Auroral arc with ray-structure, Bossekop, March 3-4, 1910, towards east

Fig. 2—The same arc as in Figure 1 towards west

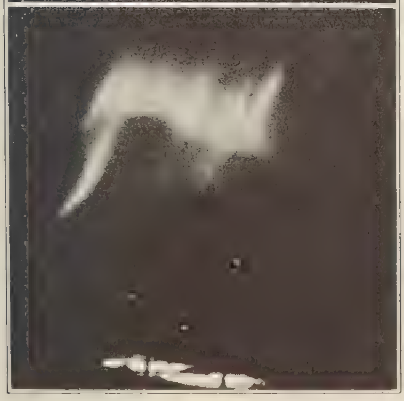


Fig. 3—Auroral curtain, Bygdó near Oslo, October 15-16, 1926, towards east

Fig. 4—Horseshoe-formed curtains, Bossekop, 1839, sketch by Bravais

thin leaves whose precipitation in the atmosphere gives rise to these curtains[3].

This explanation was a result of a very careful study of the orbits of electrons in the field of a magnetic dipole, and it was to be expected that a further study of these orbits might be useful in explaining other forms of aurora. Among such forms a very characteristic one is the horseshoe-formed curtain. Figure 4 is from a sketch of this form.

During my first researches in the years 1904-07 I found a natural explanation of this form, but did not publish anything about it. During the past few years the numerical calculations of orbits have been resumed on a large scale, thanks to subventions[4] made by "Det videnskabelige Forskningsfond af 1919," and these place the explanation on a more solid basis.

In the following pages we shall try to give an idea of this explanation. For better understanding it is necessary to give some mathematical developments; additional details under more general assumptions will, however, be given later.

2. *Differential equations of the orbits; the spaces* $Q_{\gamma,C}$—If we place the dipole as the origin of a rectangular Cartesian system of coordinates (see Fig. 5) with its axis coinciding with the Z-axis and its south pole towards the position Z, the differential equations of motion of an electron will be

[3]C. Störmer, Sur les trajectoires des corpuscules électrisés dans l'espace sous l'action du magnétisme terrestre avec application aux aurores boréales, Arch. Sci. Phys., **24** (1907).

[4]Up to the present time the Fund has given a subvention of 13,500 Norwegian crowns which is equivalent to several thousand hours of work by my assistants and myself.

$$\left.\begin{aligned} r^5\frac{d^2x}{ds^2} &= C^2[3yz\frac{dz}{ds} - (3z^2 - r^2)\frac{dy}{ds}] \\ r^5\frac{d^2y}{ds^2} &= C^2[3z^2 - r^2)\frac{dx}{ds} - 3xz\frac{dz}{ds}] \\ r^5\frac{d^2z}{ds^2} &= C^2[3xz\frac{dy}{ds} - 3yz\frac{dx}{ds}] \end{aligned}\right\} \quad \ldots\ldots\ldots(1)$$

where s is the arc of the orbit and $r^2 = x^2 + y^2 + z^2$. The constant C is given by the relation[5]

$$C^2 = Me/mv \qquad (2)$$

where m is the mass of the electron, v its velocity, and e its charge in electro-magnetic units. M is the moment of the dipole. Instead of $(m/e)v$ we can substitute another expression. Suppose the electron is moving perpendicular to the lines of force in a constant magnetic field with strength H_0; then it moves in a circle with radius ρ_0 and

$$(m/e)v = H_0\rho_0 \qquad (3)$$

which gives

$$C^2 = M/H_0\rho_0 \qquad (4)$$

an expression constantly used in my first papers on the subject.

From these equations I have found[6]

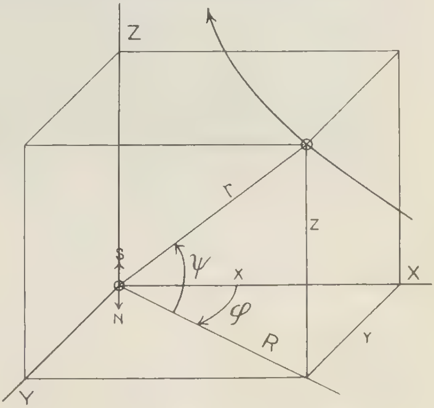


FIG. 5—System of coordinates

$$\sin\,\theta = 2\gamma C/R + C^2R/r^3 \qquad (5)$$

where θ is the angle between the tangent in the direction of motion and a plane passing through the point of contact and the Z-axis, and γ is a constant of integration which can have any value from $-\infty$ to $+\infty$.

From this equation we conclude that each orbit corresponding to fixed values γ and C can not go beyond a certain region $Q_{\gamma,C}$ described by the surface

$$r = C(\gamma \pm \sqrt{\gamma^2 + k\cos^3\psi})/k\cos\psi \qquad (6)$$

when the constant k varies from -1 to $+1$.

The discussion of the region $Q_{\gamma,C}$ is given in my first papers. It extends from the dipole to infinite distance only for $-1 < \gamma < 0$. If γ lies in the interval -1 to $-\infty$, it has a closed region containing the dipole and another region stretching to infinite distance, and if γ is positive it does not contain the dipole. Figure 6 gives sections through

[5]As is well known, the velocity of the electron v is constant.

[6]C. Störmer, Sur le mouvement d'un point matériel portant une charge d'électricité sous l'action d'un aimant élémentaire, Kristiania, Skr. Vid. selsk., No. 3 (1904).

the regions $Q_{\gamma,C}$ by a plane passing through the Z-axis, for some characteristic values of γ.

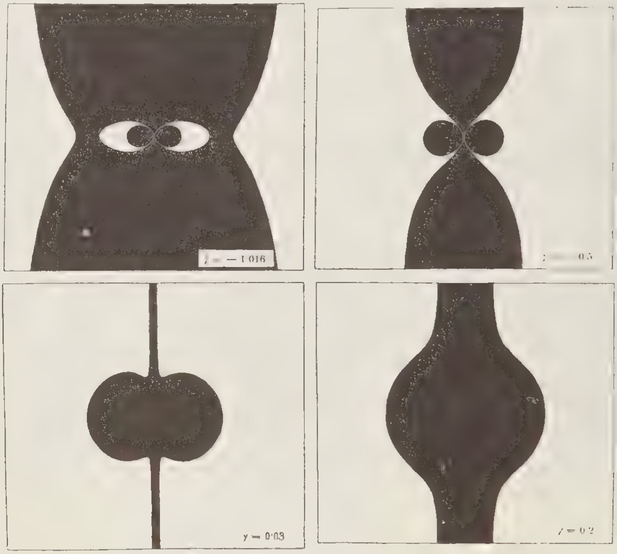


FIG. 6—Sections through region $Q_{\gamma,C}$

When the region $Q_{\gamma,C}$ reaches the dipole it becomes exceedingly narrow near it. In fact, it is enclosed between the two surfaces of revolution where $\gamma = -\gamma_1$ is negative and where k has the values 1 and -1. The section of this region by a sphere around the dipole with radius r will be enclosed between two circles with radii R_{+1} and R_{-1} where

$$R_{+1} - R_{-1} = (1/C^2)r^3 \tag{7}$$

and is thus proportional to the cube of the distance from the dipole. Figure 7 shows a section corresponding to $\gamma = -0.5$, which gives a good idea of the increasing narrowness near the dipole.

3. *Orbits passing through the dipole*—In spite of the narrowness of the spaces $Q_{\gamma,C}$ near the dipole there exists nevertheless an infinity of orbits coming from infinity and penetrating through the narrow space even as far down as the dipole. These orbits are of an outstanding importance for the theory of the aurora. In fact, for electrons with speed comparable with cathode-rays, the dimensions of the Earth are so small compared with the value of the constant C that only the orbits very near those reaching the dipole can strike the Earth and produce aurorae.

In my paper above mentioned, published in Geneva in 1907, I had found by theory and by numerical integrations a series of those remarkable trajectories. The numerical integrations have in the past few years been continued with the aid of the above-mentioned subventions.

The shape of these orbits passing through the dipole is extremely

FIG. 7—Showing narrowness of the space $Q_{\gamma,C}$ near the dipole

variable according to the different values of the constant γ. But nevertheless it is possible to get an intuitive understanding of the nature of the orbits by the following method, which I published as early as 1913. Supposing γ negative, equal to $-\gamma_1$, we let

$$x = R\cos\phi, \quad y = R\sin\phi$$

and

$$R = (C/2\gamma_1)R_1, \quad z = (C/2\gamma_1)z_1, \quad r = (C/2\gamma_1)r_1 \tag{8}$$

which is equivalent to the choice of a new unit of length, $(C/2\gamma_1)$ cm, and further

$$s = (C/8\gamma_1^3)\,\tau \tag{9}$$

Then the differential equations of the orbits will be

$$\frac{d\phi}{d\tau} = 1/r_1^3 - 1/R_1^2 \tag{10}$$

$$\left.\begin{aligned} \frac{d^2R_1}{d\tau^2} = \frac{1}{2}\frac{\partial U}{\partial R_1}, \quad \frac{d^2z_1}{d\tau^2} = \frac{1}{2}\frac{\partial U}{\partial z_1} \\ \left(\frac{dR_1}{d\tau}\right)^2 + \left(\frac{dz_1}{d\tau}\right)^2 = U + w_0^2 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{11}$$

where

$$U = -(R_1/r_1^3 - 1/R_1)^2 \tag{12}$$

and where the new constant w_0 is given by

$$w_0 = 1/4\gamma_1^2 \tag{13}$$

Thus we have first to find R_1 and z_1 as functions of τ by integration of the system (11), and if we substitute these values in the formula (10), ϕ is found by a quadrature. This gives R and z by the formula (8) and finally x and y. For the orbits passing through the dipole, I have found

$$R_1 = r_1 \cos \psi, \quad z_1 = r_1 \sin \psi \tag{14}$$

where

$$r = \cos^2\psi + (3/8)w_0^2 \, [\cos^{10}\psi + \cos^{12}\psi + (15/16) \cos^{14}\psi + (27/32) \cos^{16}\psi] + \dots \tag{15}$$

and a similar series for ϕ, both of which are usable in the vicinity of the dipole; by these series the first parts of the orbits near the dipole were calculated and the rest of the orbits, even to infinity, were found by numerical integration. A series of orbits was in this manner found[7] during 1904-07. By introducing new variables u, v, and σ defined by the

$$R_1 = e^u \cos v, \quad z_1 = e^u \sin v, \quad d\tau = e^{2u} \, d\sigma \tag{16}$$

equations a new system of differential equations can be found more convenient for numerical integration than the older one.[8] This new system has been used in the calculations since 1930, as will be mentioned later.

Before we pass to the description of the orbits found by these methods we shall first give a very useful interpretation of them by means of the system (11) and equation (10).

4. *Mechanical interpretation of the curves defined by the system (11)*—For the sake of simplicity we shall call a curve defined by the system (11) as K and a corresponding electron-orbit in space as T.

If we regard τ as time, the system (11) is the equation of motion of a material point P of mass unity which moves in a plane under the action of a force depending on the function of forces U. The curves K are, in other words, the orbits of this point P in the plane R_1Z_1. The velocity of the point P is equal to $\sqrt{U + w_0^2}$, hence equal to w_0 when the point is on the line of magnetic force $r_1 = \cos^2\psi$ and zero if the point is on the level-line $U = -w_0^2$. If we construct a series of level-lines $U = U_0 + \triangle$, $U = U_0 + 2\triangle$, $U = U_0 + 3\triangle$, . . . where $\triangle$ is sufficiently small, we get an intuitive view of the field of force in question; in fact, the force acting on the point P is everywhere perpendicular to the lines of force, directed towards increasing U and approximately inversely proportional to the breadth of the lamellæ between consecutive level-lines.

Figure 8 shows this field of force with arrows pointing in the direction of the force. We get the same directions of force if we consider the component of gravity along the surface in a land-form where the level-lines go through all points of equal height over a horizontal plane. Bearing in mind this last interpretation we can describe the field of force in the following manner: In the vicinity of the level-line $U = 0$ we have a deep valley ABC, which like a canyon grows ever steeper as we approach the dipole D from both sides. To the left of an observer looking over the land-feature from D, we have the hill EF, and symmetrical to this on the right side the hill GH. Between them the land-feature is gradually rising along I to the top of the pass L, and then gradually sinking again towards the flat plain M which continues towards infinity. The motion of the point P in this field of force is easily comprehended and resembles the rolling of a little sphere without friction on the land-form mentioned.

[7]See my paper referred to in footnote 3. Also C. Störmer, Resultats des calculs numériqus des trajectoires des corpuscules électriques dans le champ d'un aimant élémentaire, Kristiania, Skr. Vid. selsk., Nos. 4, 10, and 13 (1913).

[8]C. Störmer, Periodische Elektronenbahnen im Felde eines Elementarmagneten und ihre Anwendung auf Brüches Modellversuche und auf Eschenhagens Elementarwellen des Erdmagnetismus, Section 6, Astroph. Zs., **1**, 237-274 (1930).

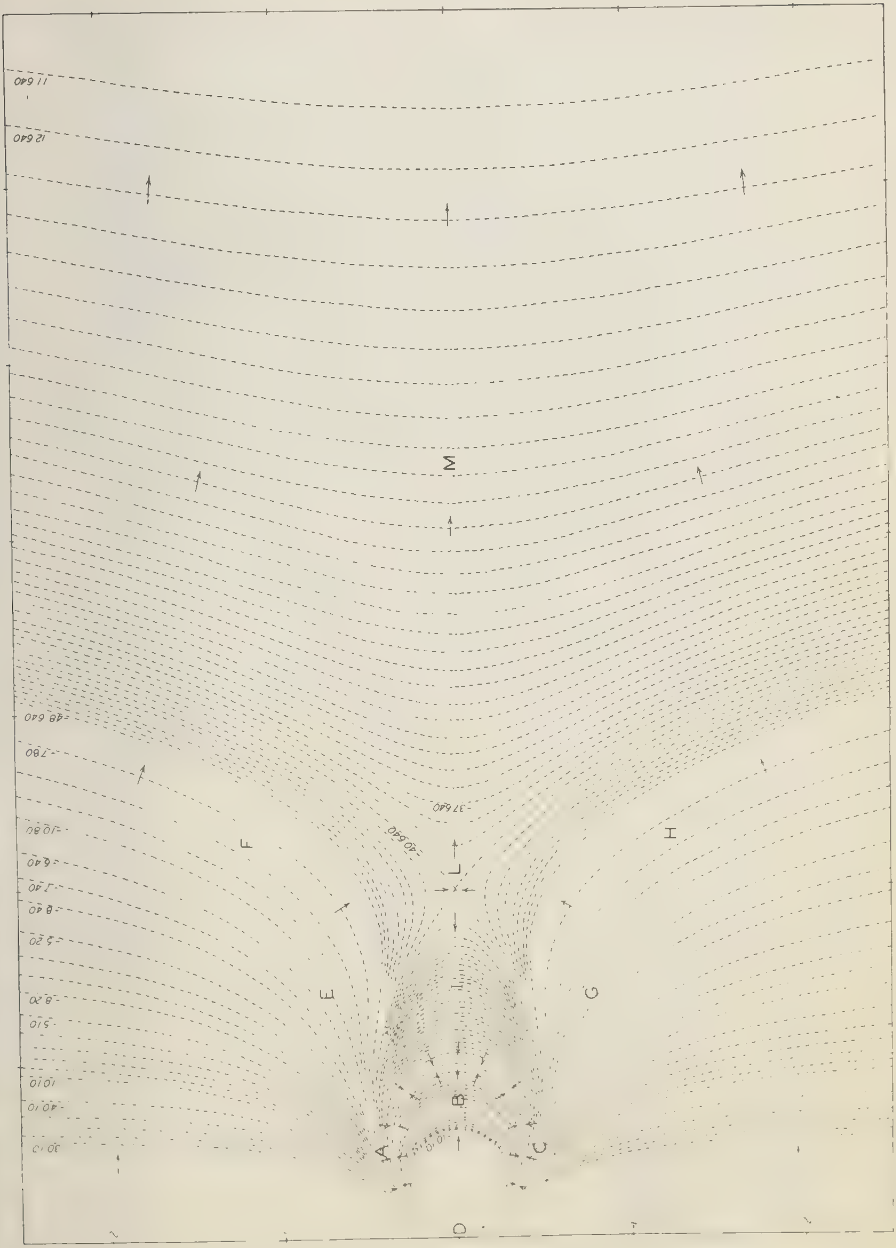


FIG. 8—Field of force in the R_1Z_1-plane

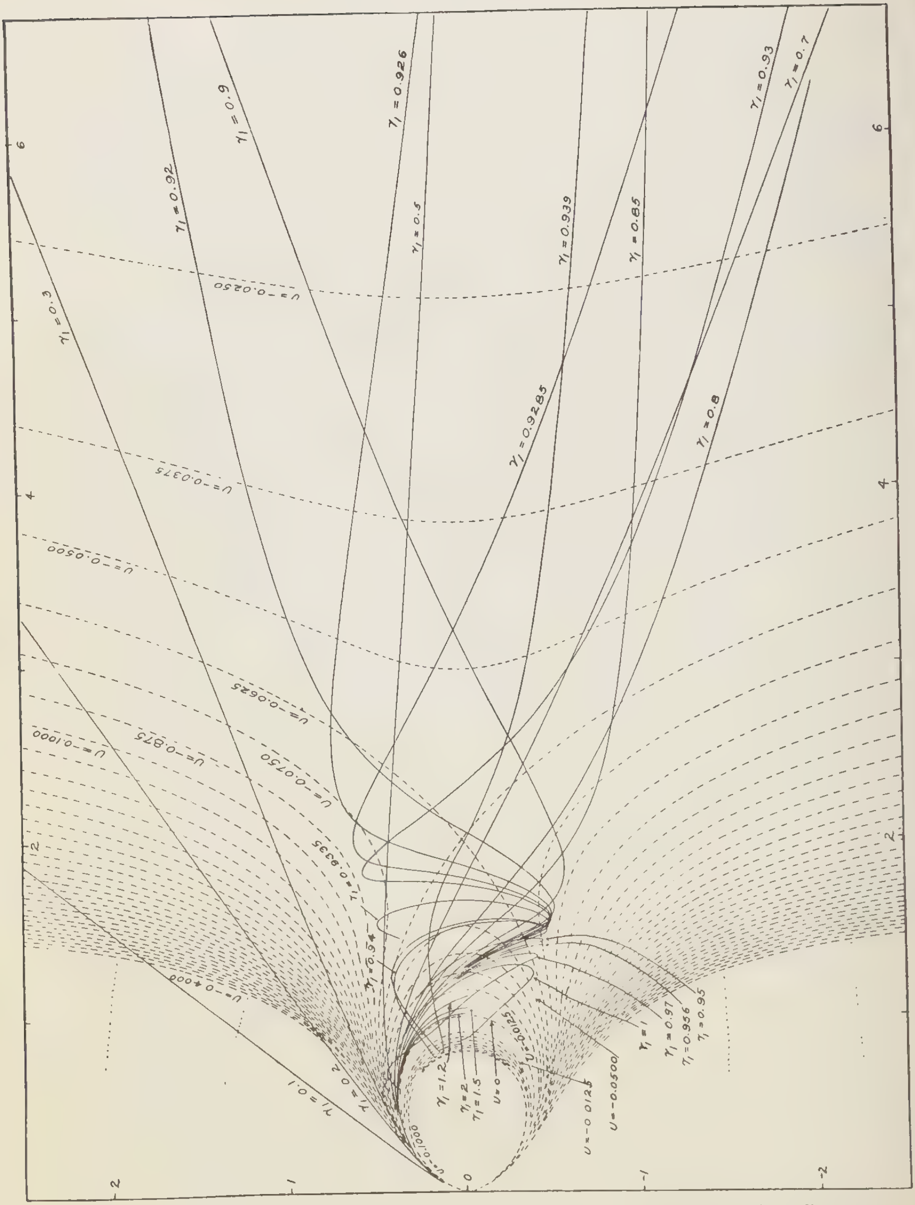


Fig. 9—K-curves through the origin (the level-lines U=constant are dotted)

The trajectory is everywhere curved in the direction of force, that is, downwards and the point can not pass over the level-line $U = -w_0^2$, where the velocity becomes zero. When P reaches this limiting level-line, it falls down again following exactly the same path in the opposite direction. The same orbit can be described by the point P in two opposite directions.

Let us now consider the trajectories corresponding to electron-orbits through the dipole. They are defined near the origin by the series of equation (15). From this series we see that they have a very high contact with the magnetic line of force $r_1 = \cos^2 \psi$, that is, with the level-line $U = 0$, in the origin and they can be considered *as trajectories of the point P when this point is shot out from the origin along the line of force and with velocity* $w_0 = 1/4\gamma_1^2$. We shall use this interpretation in the following discussion.

5. *Discussion of the calculated K-curves through the origin*—Figure 9 shows the K-curves[9] through the origin calculated during 1904-07, a work of more than 700 hours. If we remember the mechanical interpretation of these curves and have in mind the resemblance to the rolling of a small sphere over the land-form with level-lines U = constant, the form of the K-curves is easily understood. If γ_1 is small, the initial velocity w_0 is great and the point will rush high up on the hill EF before it rolls down again.

When γ_1 increases to 0.2, 0.3, 0.4, and 0.5, the velocity w_0 decreases and the point mounts lower and lower on the hill EF, until finally it only touches it and continues right over the pass I.

For $\gamma_1 = 0.7$ the point P begins to enter the other hillside GH, but now the velocity w_0 is so small that the following curves only ascend a little way before going down again. For $\gamma_1 = 0.92$, 0.926, 0.9285, and 0.93, the point P advances for a second time on the hillside EF, rolls down again, and then goes to infinity.

[9] C. Störmer, Sur le mouvement des corpuscules électriques dans le champ d'un aimant élémentaire et la forme de leur trajectoire à leur arrivée à l'aimant, Arch. Sci. Phys., **35**, 483-489 (1913).

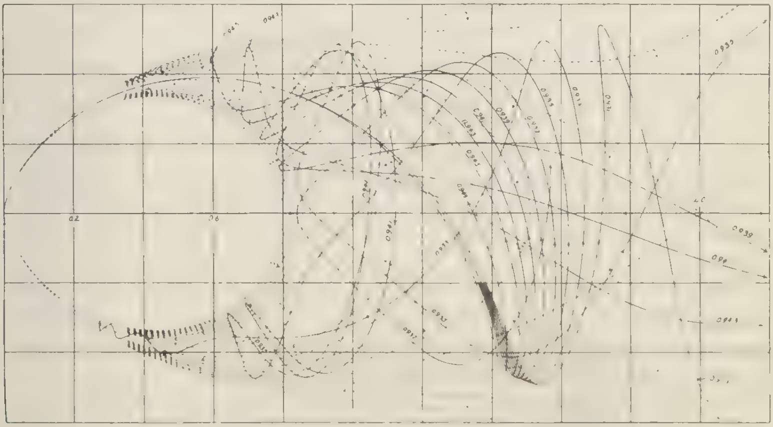


FIG. 10—Bundle of K-curves for values of γ_1 from 0.931 to 0.949

But for the next trajectory, $\gamma_1 = 0.9335$, the point P can not reach the pass L, but rolls back again. The same thing happens for all following K-curves: They can not reach the pass the first time they approach it, but it happens that they go through it later, as, for instance, when $\gamma_1 = 0.939$; if they traverse the pass they continue towards infinity.

If γ_1 is greater than unity, the K-curve will never come out of a closed region. In this case the point P will move up and down in the closed narrow valley round the level-line $U = 0$.

In the recent numerical integrations begun in 1930,[8] we have calculated u and v directly from their differential equations; this has certain advantages corresponding with the older methods. From u and v we determined R_1 and z_1 by equations (16). The resulting curves are shown in Figures 10, 11, and 12. We have calculated two bundles, the first for

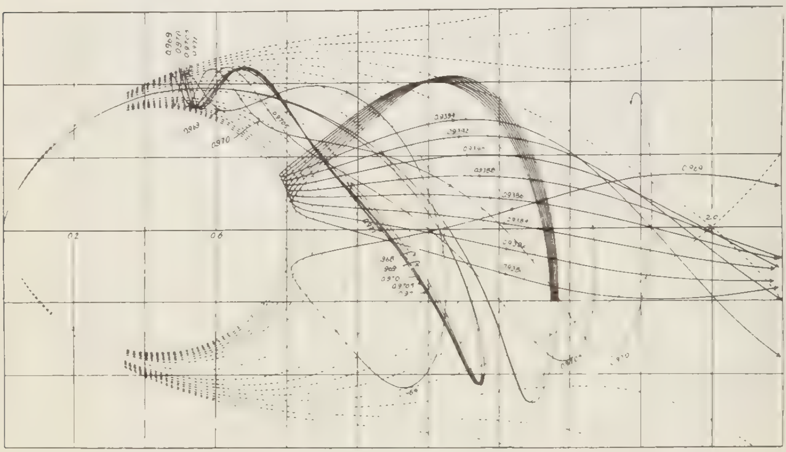


Fig. 11—Bundles of curves near $\gamma_1=0.970$ and $\gamma_1=0.939$

values of $\gamma_1 = 0.931, 0.933, 0.935, 0.937, 0.939, 0.941, 0.943, 0.945, 0.947$, and 0.949, and the second for values of $\gamma_1 = 0.968, 0.969, 0.970, 0.971$, and 0.972. The calculation was started at the origin and continued until the curves had passed the R_1-axis with an accuracy of seven decimals, and then continued with six decimals. The first point of intersection with the R_1-axis and the direction of the tangent at this point was found for each trajectory, in order to interpolate new curves between them for other values of γ_1. These new curves could then be started from the R_1-axis, thus saving the labor of calculations from the origin to this axis.

The first bundle is shown by Figure 10 and the second by Figure 11.

A good check on the accuracy of the numerical calculations was had in the new calculations of the two curves for $\gamma_1 = 0.939$ and $\gamma_1 = 0.970$, which were quite independent of those made in 1904-07. Thus plotting the calculated points of the old and new curves on coordinate-paper with a scale of unity equal 500 millimeters, it was impossible with the eye to discover any difference.

Let us now discuss the curves by using the mechanical interpretation.

The curve $\gamma_1 = 0.931$ has still enough energy to go over the pass, but the next one $\gamma_1 = 0.933$ returns to the valley and penetrates far into the deep canyon C, from which it later goes out again, but because of the numerical complications the calculation has not been continued so far. The next one $\gamma_1 = 0.935$ makes several loops up and down the walls of the valley before it happens to hit the pass under such conditions that it goes over it towards infinity. The same happens for the curves $\gamma_1 = 0.939$, $\gamma_1 = 0.941$, and $\gamma_1 = 0.943$, and perhaps also for other curves, although this can not be determined definitely by the calculations thus far made.

Figure 11 shows the second bundle. Here the five curves follow each other closely and begin first to diverge in the upper part of the valley A, and when they again leave this valley the divergence becomes very great. The Figure also shows the curve $\gamma_1 = 0.9705$. The curve $\gamma_1 = 0.969$ happens to go over the pass towards infinity, but what the other curves do is unknown.

We have also calculated other bundles, but the calculation should be extended later because it is difficult to arrive at definite conclusions.

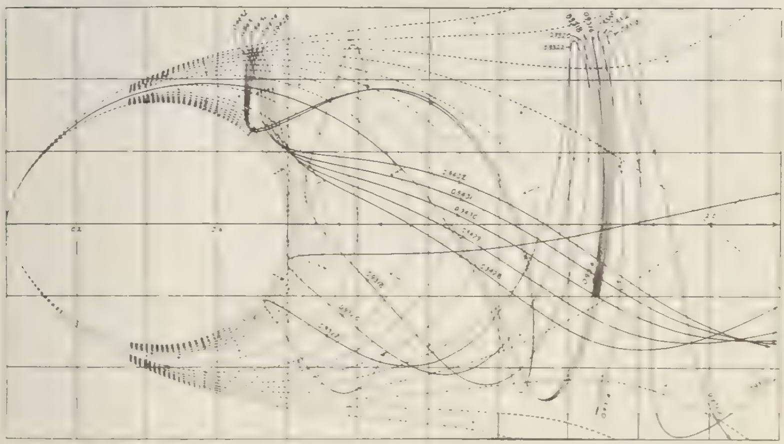


FIG. 12—Bundles of curves near $\gamma_1 = 0.9316$ and $\gamma_1 = 0.9430$

Figure 12 shows a bundle consisting of the curves when values of γ_1 are 0.9310, 0.9312, 0.9314, 0.9316, 0.9318, 0.9320, and 0.9322. Among these the first two surmount the pass the first time they reach it, while the others return. One of the curves, $\gamma_1 = 0.9320$, goes straight through the pass the second time, but what the other curves do is unknown. The transition between the curves which traverse the pass the first time and the curves which do not is particularly interesting and requires further researches.

Figure 12 shows also a bundle where γ_1 has the values 0.9428, 0.9429, 0.9430, 0.9431, and 0.9432, which together with the bundle in Figure 11 for values of $\gamma_1 = 0.9380$, 0.9382, 0.9384, 0.9386, 0.9388, 0.9390, 0.9392, and 0.9394, is very interesting, as the corresponding orbits of electrons in space afford a remarkable explanation of the horseshoe-formed auroral draperies. I hope later to be able to calculate still more curves on both

sides of these interesting bundles in order to get a clear idea of what happens.

6. *The corresponding orbits in space*—Let us suppose that all K-curves reaching the origin from the positive side of the Z-axis are known. The corresponding orbits in space are then given by the formulae

$$x = (C/2\gamma_1)R_1 \cos \phi$$
$$y = (C/2\gamma_1)R_1 \sin \phi$$
$$z = (C/2\gamma_1)z_1$$

where the angle ϕ is found by numerical quadrature of the equation

$$\frac{d\phi}{d\tau} = 1/r_1^3 - 1/R_1^2$$

For a given K-curve with motion along it in the direction of the dipole, we then find a corresponding orbit T_0 in space, corresponding to a motion towards the dipole. Symmetrical to T_0 with respect to a plane through the Z-axis is another orbit T_0' corresponding to a motion away from the dipole, and symmetrical to these two orbits with respect to the XY-plane we have two other orbits reaching the dipole from the negative side of the Z-axis. Finally, in addition to each of these four orbits, we have all those obtained by rotating one of them through an arbitrary angle around the Z-axis.

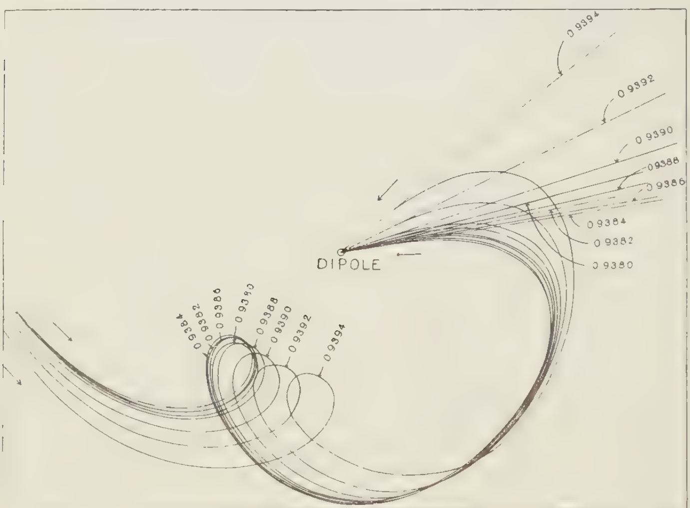


FIG. 13—Projection on the XY-plane of orbits corresponding to the bundle near $\gamma_1 = 0.939$ (unit of length C centimeter)

In the following we consider only the orbits T_0. For γ_1 between zero and 0.93 the discussion of these orbits with applications to the polar aurora has been published in earlier papers.[1] Here we shall only consider the orbits corresponding to the bundle near $\gamma_1 = 0.939$ with application to the horseshoe-formed draperies.

Figure 13 gives the projection on the XY-plane of these orbits, corresponding to a fixed velocity and coming from points in the Z-plane very far away. Figure 14 shows a stereoscopic view of a wire model of the same orbits in space. We see here something characteristic of this bundle, of the bundle near $\gamma_1 = 0.943$, and of an infinity of analogous bundles. If we follow the position of the plane through the Z-axis

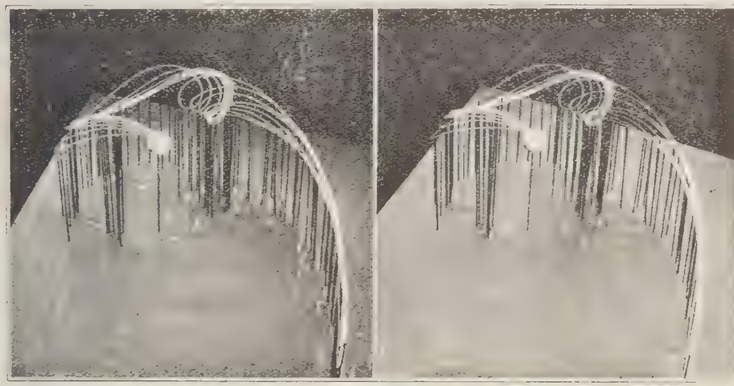


FIG. 14—Stereoscopic view of a wire model of the orbits of Figure 13 in space

tangent to the orbit at the dipole, as a function of γ_1, this plane will for increasing values of γ_1 first swing clockwise, reach a certain position corresponding to a maximum of ϕ, and then swing back again anti-clockwise.

If we cut the orbits by a small sphere with center in the dipole and plot the points of intersection, we shall then get a horseshoe-formed line as in Figure 15. The two branches of the horseshoe will be a small distance from each other; in fact, when r_1 is small we can reject in formula (15) the higher terms $\cos^{12}\psi$, etc., which gives $r_1 = \cos^2\psi$, and from this $\sin\omega = \sqrt{2\gamma_1 r/C}$, where r is the radius of the sphere and ω is the angular distance from the Z-axis to the point of intersection. When γ_1 increases, this distance increases also.

In the above discussion we have only considered a bundle of orbits where the electrons all have the *same* velocity. How the discussion must be modified if the velocity changes a little from one orbit to another will be shown in a later memoir.

7. *Application to the polar aurora*—If we apply these results to the corpuscular theory of aurora in its simplest form, where the Earth's magnetism is considered equivalent to that of a dipole and where each electron is supposed to move independently of the others, the large value of the constant C is one of the first characteristic results.[1] This means that the dimensions of the Earth are very small compared with the dimensions of the horn seen in Figure 7. From this it follows that only the orbits very near those through the dipole can reach the Earth and be the cause of the aurora; in other words, among the great many different trajectories of electrons toward the Earth, *terrestrial magnetism will filter*

out only a very small number consisting of those in the immediate vicinity of the trajectories through the origin. This is the reason why those trajectories play such a great rôle in the theory of the aurora.

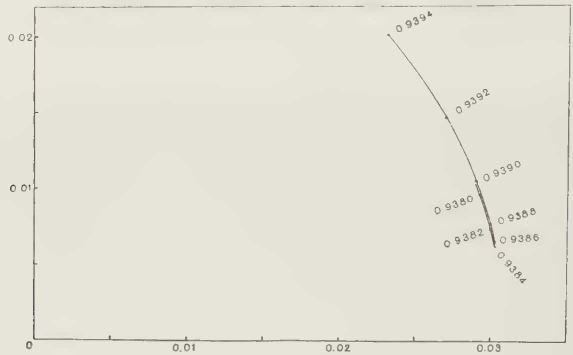


FIG. 15—Horseshoe-formed projection on a small sphere of the orbits of the bundle (unit of length is C centimeter and the distance between the two branches is smaller than in the figure)

Let us now consider a bundle of trajectories towards the Earth containing among the trajectories also those of the bundle near $\gamma_1 = 0.939$ This bundle or a part of it will then be filtered out and the line of precipitation in the Earth's atmosphere will then be seen just as a horseshoe-formed curtain as in Figure 4.

We have probably here an explanation, at least qualitatively, of those remarkable curtain-forms, or at all events a working hypothesis which it is worth while to follow.

UNIVERSITY OF OSLO,
Oslo, Norway

THE TEMPERATURE OF THE AURORAL REGION DETERMINED BY THE ROTATIONAL SERIES OF THE NEGATIVE NITROGEN-BANDS

By L. Vegard

1—*Preparations and preliminary work*

When in 1921 the spectrographic work on the auroral spectrum was taken up in a systematic way, one of the problems to be dealt with was to determine the temperature of the auroral region by means of the rotational nitrogen-bands.

In a laboratory, where we can produce intense sources of light and use spectrographs with sufficiently large dispersion to separate the individual rotational components, the determination of the temperature of the light-source from the band-spectra may be carried out without any great difficulty. In the case of the aurorae, however, the luminescence is so faint that we must use spectrographs with a dispersion too small for the separation of the individual rotational components.

Even if we cannot obtain ideal auroral spectrograms, we might still be able to measure the temperature by considering the variations of the rotational striations as a whole. After I obtained my first spectrogram in 1923 I began investigations in this direction after the following plan.

The nitrogen in a vertical glass tube—which might be put into a Dewar receiver containing liquid air or other cooling liquids—was exposed to a bundle of cathode rays. The cathode rays came from a Wehnelt cathode, placed in an upper discharge-tube and in such a way that a fairly narrow bundle of rays from the active cathode-area was made to pass through a narrow hole in a metal cylinder which separated the discharge-tube from the lower receiver.

The luminescence produced by the cathode rays was analysed by spectrographs with nearly the same dispersion as that used for the study of the auroral spectrum. In this way we were able to examine the luminescence from a light-source whose temperature could be changed in a known way. By comparing the development of the rotational band-striations from the auroræ with that of the spectra obtained from the artificial source of known temperature, we should be able to draw definite conclusions regarding the temperature of the upper atmosphere.

In 1923 spectra from nitrogen exposed to cathode rays were taken at room temperature and at that of liquid air, and then compared with the spectrograms obtained from the auroræ.

Some preliminary results from these investigations were described in papers published in 1923.[1] In these papers a merely qualitative comparison was made, which showed that the temperature was considerably lower than ordinary room temperature. These investigations were not carried further at that time on account of other work, especially the study of the luminescence from solidified gases which has absorbed much of my time from 1923 to the present day.

Meanwhile the spectrographic work was continued at Tromsö during

[1] L. Vegard, Phil. Mag., **46**, 577-604 (1923); Zs. Physik, **16**, 367-390 (1923).

the years 1923-26. With a large spectrograph we obtained a number of spectrograms which gave some of the stronger negative nitrogen-bands with a photographic density which was suitable for measuring the intensity-distribution within the striation due to the rotational bands.

By that time the structure of the nitrogen-bands was analysed and the series formulæ determined. The second positive group was analysed by P. Lindau[2] and the negative by Maria Fassbender.[3] It appears from this analysis, that the fairly sharp heads obtained by small dispersion are due to the *P*-branch.

In order that the method of measuring the temperature of the upper atmosphere may be reliable, it is essential that the development of the *R*-striation by the conditions under which light is produced, be a function of temperature and be independent of the pressure and velocity of the exciting rays.

Being much occupied with other problems, I suggested to one of my collaborators, J. Aars, that he should take up experimental investigations along these lines. By means of an experimental arrangement similar to that previously described, he was to investigate the development of the *R*-striations at the temperature of liquid air as well as at room temperature and to use spectrographs with nearly the same dispersion as that used for the auroral spectrograms. Thus he would obtain photographic records which might be used for a quantitative determination of the temperature of the upper atmosphere.

These investigations were begun in 1926 and the results were communicated for publication in 1928.[4] In accordance with my previous results, he found that the *R*-striations of the bands were very much shorter at the temperature of liquid air than at room temperature, and in addition he found *that at a certain temperature of the gas, the development and position of any striation are independent of the pressure of the gas and the velocity of the cathode rays.*

This result indicates that the temperature of the gas along the ray-bundle is not essentially increased through the bombardment of the rays, and consequently the effective temperature of the light-source should be about $+18°$ C at room temperature and about $-185°$ C at that of liquid air. *The temperature derived from the rotational bands of the auroral spectrum should give the temperature of the auroral region as it is without the electric rays which produce the auroræ.*

It was then my intention to work out the results of all my observational material relating to the auroral spectrum, including also the determination of the temperature by means of the auroral nitrogen-bands and the results obtained by J. Aars. Owing to various other duties and problems which took my time, the working up of this material has advanced rather slowly and therefore the results of the quantitative temperature-measurements first appear in connection with a complete account of the observations from the period 1921-26.[5]

[2]P. Lindau, Über den Bau der zweiten positiven Gruppe der Stickstoffbanden, Zs. Physik, **30**, 73 (1924).

[3]M. Fassbender, Untersuchungen über das negative Stickstoffspektrum, Zs. Physik, **30**, 73-92 (1924).

[4]J. Aars, Ann. Physik, **1**, 216-228 (1929).

[5]This account is communicated to Det Norske Videnskaps akademie, to be printed in Geophys. Pub.

2—*General remarks regarding the method used in the determination of temperature*

The temperature-determinations will be based upon the band 4278 of the negative nitrogen-group. This band-system originates from the positive nitrogen-ion N_2^+ and corresponds to a transition to the normal Σ-state from an upper level usually taken to be a Σ-state.

According to the quantum theory of band-spectra, the intensity-distribution within the R-branch is given by the equation[6]

$$I = c\, j\, e^{-\kappa(j+1/2)^2} \tag{1a}$$
$$\kappa = h^2/8\pi^2 J\, k\, T \tag{2}$$

where j is the rotational quantum number corresponding to the *upper* electronic level, h is Planck's constant $=6.55\times 10^{-27}$, I is the moment of inertia of the nitrogen-ion N_2^+ in the upper state $=13.4\times 10^{-40}$, k is Boltzman's constant $=1.37\times 10^{-16}$, and T is the absolute temperature.

Equation (1*a*) may also be written in the form

$$\ln\ (I/j) = c'[-\kappa(j+1/2)^2] \tag{1b}$$

The quantum-numbers m used by Fassbender differ from j by an additional constant. In fact we have $m=(j+1/2)$ and equation (1*a*) may be written

$$I = c\ (m-1/2)e^{-\kappa m^2} \tag{1c}$$

Investigations on the relation between temperature and the development of rotational bands were made by Birge[7] and in recent years by Ornstein[8] and v. Wijk[9], who find that the intensity-distribution of the components of the R-branch obey a law of the type given by equation (1).

In the case of our auroral spectrograms where the R-branch takes the shape of a continuous band, we might adopt the following procedure. In formula (1) regard the quantum-number j (or m) as a quantity which varies continuously. We measure the intensity-distribution within the R-branch as a function of j. Plotting ln (I/j) against $(j+1/2)^2$ we should get a straight line, from the slope of which κ and T can be found.

We may also determine T from the position of the intensity-maximum of the R-striation. Differentiating equation (1*c*) with respect to m the condition of maximum gives

$$T = (h^2/8\pi^2 k\ J)\ (2m_1^2 - m_1) = 2.96\ (2m_1^2 - m_1) \tag{3}$$

where m_1 is the value of m which gives maximum of intensity.

In order to find the quantum-number (m) corresponding to a given point of the R-branch, we measure the position ($\triangle\lambda_R$) of the point relative to the head of the P-branch, the wave-length λ_p of which is known.

The wave-length λ_R of the point in the R-branch is

$$\lambda_R = \lambda_p - \triangle\lambda_R \tag{4}$$

[6]Compare W. Weizel, Bandenspektren, Handb. Experimental physik, Ergänzungswerk **1**, 191, 166 (1931).

[7]Astrop. J., **55**, 273-290 (1922).

[8]L. S. Ornstein und W. R. v. Wijk, Untersuchungen über das negative Stickstoffbandenspektrum, Zs. Physik, **49**, 315-322 (1928).

[9]W. R. v. Wijk, Zs. Physik, **59**, 313-319 (1930).

From the Fassbender analysis we obtain the value of m corresponding to a given wave-length λ. Having determined the intensity-distribution within the R-branch as a function of λ we obtain in this way corresponding values of I and j (or m) and the curve $[\ln(I/j)-(j+1/2)^2]$ can be constructed.

Using that value m_1 corresponding to maximum intensity, we may determine the temperature by means of equation (3).

These "absolute" determinations of the temperature from the position of the intensity-maximum may now be corrected by comparison with the spectra from the sources of known temperature.

3—*Results of our temperature-determinations; spectra and intensity-curves*

The auroral spectrograms obtained with the large glass spectrograph show some of the strongest heads of the negative nitrogen-bands, but only the band 4278 gives the R-branch with photographic density sufficiently strong for intensity-measurements.

From six plates, we selected three which gave the best conditions for measurements. These spectra are indicated by A, B, and C;[10] these result from 44, 18.5, and 44 hours of exposures during effective auroral displays during October 9 to December 31, 1923, January 7 to 15, 1924, and January 16 to April 12, 1924, respectively. B and C, having been taken with a cylindrical lens in front of the plate, give lines which are less sharp than those of the spectrum A taken in the ordinary way. At the wave-length 4278 the auroral spectrograph had a dispersion of 27 Å per mm. Registrations of the 4278-band are given in Figure 1.

From plates obtained by J. Aars we selected two which were taken with the large glass spectrograph with a dispersion at 4278 of 34 Å per mm. The registrations of the 4278-band are given in Figure 1.

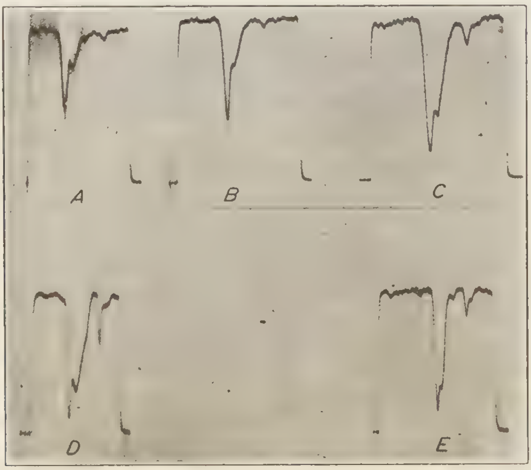


FIG. 1

[10]Photographic reproductions of the spectrograms will be found in the complete account referred to.

The diagram *D* corresponds to room temperature and E to the temperature of liquid air.[11]

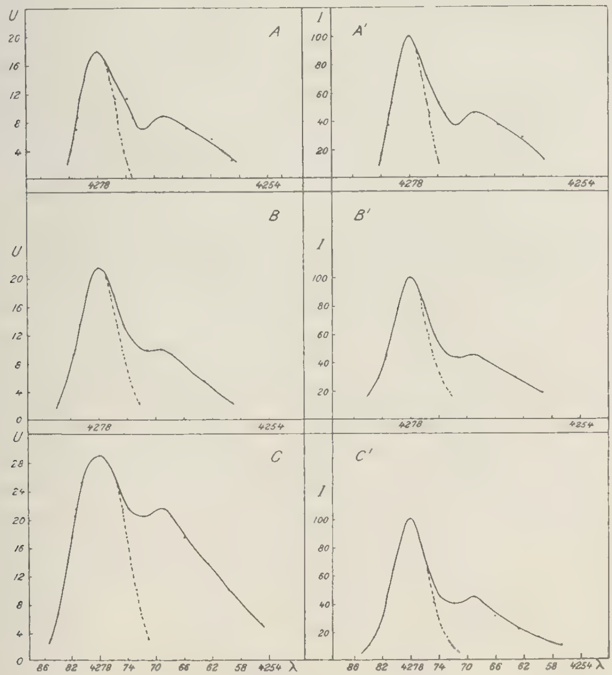


Fig. 2

The curves as registered were measured with a comparator. The diagrams were placed on a table which could be moved perpendicularly to the motion of the microscope. From the known dispersion, curves were constructed giving the deflection (u) of the microphotometer as a function of the wave-length. The left part of Figure 2 gives the curves thus transformed for the auroral spectra. Figure 3 gives the corresponding curves for the spectra *D* and *E*. The position of the intensity-maximum can be directly measured from these curves.

In order to apply the method of determining the temperature by means of the intensity-distribution law, the relative intensity-distribution within the *R*-branch was found for the three auroral spectra. This was done in the usual way by means of the intensity-scale which was photographed on each of the three plates. The intensity-curves are indicated by A′, B′, and C′ and are shown at the right in Figure 2. The maximum intensity of the *P*-head is in all cases made equal to 100.

4. *The temperature determined from the position of the maximum intensity*

From the structure analysis of Fassbender, we estimate the wave-

[11]In the paper of J. Aars referred to reproductions of a number of his spectrograms will be found.

length of the *P*-head to be 4278 from microphotometric curves (or the transformed curves Figures 2 and 3). We then find the wave-length corresponding to the intensity-maximum, and from the Fassbender tables we take out corresponding values of the quantum-number (m). The temperature is calculated from equation (3).

In the case of the auroral bands we took the mean value of the three spectra. The results are given in Table I.

TABLE I

Element	λ_{max}	m_1	T
Room temperature.......	4268.3	6.6	238° K
Auroral region..........	4269.0	6.0	195° K
Liquid-air temperature...	4272.0	2.85	40° K

It appears that in the case of the artificial light-sources the temperature derived from the band-spectra is too low. This result in connection with those of Aars[4] shows that the electric rays under the conditions of our experiments do not *produce any marked increase of temperature*, and the effective temperature of the artificial light-sources may be put equal to that of the main bulk of the gas surrounding the cathode-ray bundle.

This result also shows that the cosmic rays, producing the aurora, should not essentially increase the temperature as it is measured from the rotational bands.

For the "absolute" determination of the temperature by means of the position of the maximum intensity, there is a systematic error which in some manner results from the small dispersion used. As the dispersion in the case of the auroral spectra is about the same as that of the artificial light-sources, all spectra should be comparable and we may correct the auroral temperature by means of the spectra from the light-sources of known temperature, which may be put equal to 291° K and 85° K.

By simple interpolation we find the correction for the auroral temperature to be +51° which added to the value of Table I gives a temperature of the auroral region equal to 246° K or −27° C.

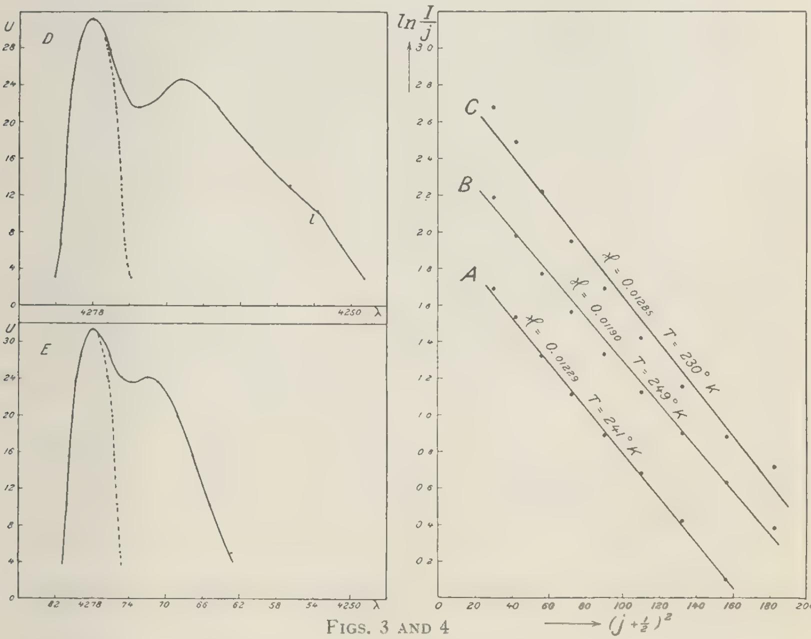
We may also undertake this interpolation in the following way. Putting T equal to 291° in equation (3) we find the quantum-number (m_1) of the intensity-maximum at room temperature to be $m_1 = 7.27$, which corresponds to wave-length $\lambda = 4267.55$. This means that the wave-length of the intensity-maximum was found too large by the amount $\triangle\lambda = 0.75$ Å. This correction $\triangle\lambda$ applied to the auroral spectra and to that of liquid-air temperature leads to the values given in Table II.

TABLE II

Element	λ_{max}	m_1	T	t
Room temperature..........	4267.55	7.27	291° K	+ 18° C
Auroral region.............	4268.25	6.65	242° K	− 31° C
Liquid-air temperature......	4271.25	3.69	70° K	−203° C

5—*The temperature of the auroral region found from the intensity-distribution within the R-branch*

The curves A′, B′, and C′ of Figure 2 give the relative intensity within the R-branch as a function of λ and from the Fassbender tables we find the relation between I and the quantum-number m (or j.) The results are given in the Table III. The first and second columns give the quantum-numbers j and the corresponding wave-length values within the region of the R-branch for which the intensity can be fairly accurately measured. For each of the three spectra A, B, and C are given corresponding values of I and $\ln \frac{I}{j}$.



FIGS. 3 AND 4

TABLE III

Intensity-distribution within the R-branch (4278) of the auroral spectrum

j	λ	A		B		C	
		I	$\ln \frac{I}{j}$	I	$\ln \frac{I}{j}$	I	$\ln \frac{I}{j}$
5	4269.49	44.5	2.19	44.5	2.19	44	2.18
6	4268.42	45.5	2.03	43.5	1.98	44	1.99
7	4267.29	43	1.82	41	1.77	39	1.72
8	4266.10	40	1.61	38	1.56	34	1.45
9	4264.85	36	1.39	34	1.33	29.5	1.19
10	4263.54	32.5	1.18	30.5	1.12	25	0.92
11	4262.16	27.5	0.92	27	0.90	21	0.65
12	4260.72	22	0.60	22.5	0.63	17.5	0.38
13	4259.21	14	0.08	19	0.38	16	0.21

The relation between $\ln \frac{I}{j}$ and $(j+1/2)^2$ is illustrated in Figure 4. It appears that in the case of spectrum A the points lie almost exactly on a straight line; in the case of B and C there are some deviations, which are probably due to the fact that the two spectra were taken with a cylindrical lens in front of the plate. It might of course also be caused by real changes of temperature in the auroral region. In the case of spectra B and C, we draw the straight lines so as to give the average slope. The temperatures determined from the slope of the lines of Figure 4 are given in Table IV.

TABLE IV

Spectrum	κ	T	t
A	0.01229	241° K	−32° C
B	0.01190	249° K	−24° C
C	0.01285	230° K	−43° C
Means..........		240° K	−33° C

6—*Discussion of the results*

The "absolute" determination of the temperature of the auroral region by means of the intensity-distribution is independent of any comparison with sources of known temperature, but we notice the remarkable fact that this absolute determination gives almost exactly the same temperature as the relative determination obtained by comparing the position of the intensity-maximum with that of the light-sources of known temperature.

The "relative" determination by means of the spectra obtained at room temperature and at that of liquid air gave a temperature of the auroral region equal to 244° K or −29° C. The absolute determination gives the average value 240° K or −33° C.

The average temperature of the auroral region obtained by the two methods is 242° K or −31° C.

Although there may be an error of some degrees in our determination, this fairly accurate knowledge of the temperature in the auroral region will be of the highest importance for the physics of the upper atmosphere.

Thus the high temperature assumed by Lindemann and Dobson[12] to account for the appearance and distribution of meteors does not exist, and as pointed out in previous papers[13], we have to account for the meteor-distribution by the elevation of matter due to electric fields.

The temperature is derived from auroral band-spectra obtained by exposures lasting for several weeks or months. It is therefore to be considered as an average temperature for fairly long periods. From the statistical treatment of the height of the auroræ and of the intensity-distribution along the streamers,[14] we may estimate that the luminescence by long exposures corresponding to a height-interval of between 100 and

[12] F. A. Lindemann and G. Dobson: Proc. R. Soc., A, **102**, 411-437 (1922).

[13] L. Vegard: Phil. Mag., **46**, 193-211 (1923); Zs. Geophysik, **6**, 42-56 (1930).

[14] L. Vegard and O. Krogness, Position in space of the Aurora Polaris, Geofys. Pub. **I**, No. 1 (1920).

125 km; and according to our measurements the average temperature of this interval should be about $-30°$ C.

It is, however, very likely that the temperature may undergo great changes, and that the auroræ appearing early in the evening—as well as the sunlit auroræ—would give a higher temperature than those appearing in the middle of the night. It is to be expected that the temperature at a certain height may increase with the polar distance and may at a certain locality vary with the season.

7—*The sound phenomena and atmospheric temperature*

The question regarding the temperature-distribution of the atmosphere has also an interesting bearing on the interpretation of the phenomena connected with the transmission of sound produced by explosions.

From direct observation we know that the temperature in the stratosphere keeps a fairly constant value of about $-50°$ C up to an altitude of 38 km; but in order to explain the sound-phenomena it has been commonly assumed that above that height a rapid increase of temperature takes place. On the other hand we found in the auroral region a temperature of about the same magnitude as that of the isothermic stratospheric layer. If the reflection of sound-waves—which is supposed to occur at an altitude of 40-50 km—were due to change of temperature, we should have a sudden increase at 38 km followed by a rapid decrease. Such a distribution is very unlikely and I think that the observed sound-phenomena are not at all due to temperature-variations. This interpretation is based on the assumption that the sound-waves throughout the atmosphere are propagated with a velocity

$$V = V_{\circ} \sqrt{T/T_{\circ}}$$

where T is the absolute temperature.

Now a formula of this type does not necessarily hold for propagation through the atmosphere where the density diminishes rapidly. At any rate it is certain that the *propagation breaks down* when the pressure gets below a certain limit.

In order to test this point some simple experiments were recently made at our laboratory. A loud-speaker of suitable form was put into a vessel which could be evacuated. The sound was produced by a high-frequency alternating-current. Inside the vessel, and at some distance from the loud-speaker we placed a microphone connected to a telephone outside the vessel. An estimate of the intensity of the sound reaching the microphone was obtained by means of a variable shunt-resistance which was diminished until the sound disappeared. Details regarding the results of the experiments will be given elsewhere.

In this connection we may merely mention the following facts. By diminution of pressure the transmitted energy remains at a high value until a pressure of 1-2 cm is reached when the sound-intensity rapidly falls off, and becomes practically zero at a pressure of order of about 1 mm of mercury. Now a pressure varying from one cm to one mm is found in the height-interval 30-45 km. *In this interval the sound-waves break down and the energy will be partly absorbed and partly reflected.*

The breaking down of the transmitted energy should according to

some very early measurements of Krajewitsch[15] be accompanied by a rapid fall in the velocity of propagation. At a pressure of 2.2 mm he found a velocity of 82 meters per second. This rapid fall of velocity cannot be compensated for by any reasonable increase of temperature. These simple considerations thus lead to the conclusion that, independent of any assumption as regards temperature, the sound-waves are restricted to a layer below say 40 km. A detailed explanation of the distribution of sound-intensity around an explosion will require more exact study of the behaviour of sound-waves when they are transmitted in the air towards rapidly decreasing density and especially in the limiting layer where transmission ceases.

In this connection we merely wish to point out that the reflection of sound from the upper atmospheric layer gives no argument for the assumption of a rapid increase of temperature above 40 km.

[15]Handb. Physik, **8**, 625.

Physical Institute University
Oslo, Norway

THE COSMIC-RAY OBSERVATORY ON THE HAFELEKAR (2300 METERS) NEAR INNSBRUCK (AUSTRIA) AND ITS FIRST RESULTS

By Victor F. Hess

In spite of the efforts of many prominent physicists from all parts of the world the main problems of the cosmic radiation which was discovered twenty years ago are still unsolved.

While some investigators analyzing the penetrating power of the cosmic rays in various absorbing materials by the use of the ionization method (Kolhoerster, Hoffmann, Steinke, Millikan, and others) and by use of the Geiger-Mueller tube-counter (Bothe and Kolhoerster, Rossi, L. M. Mott-Smith, etc.) have come to very interesting conclusions as to the origin of the cosmic rays, it can be said that these conclusions are as yet by no means definitely proved and partly, at least, contradict each other.

The question whether the radiation has its origin in the inter-stellar space (as suggested by Millikan) or within the stars or nebulae (Nernst, Jeans, etc.) is still not definitely answered.

Another question is whether this radiation consists of photons (quanta), of charged corpuscles (electrons or protons or both), or of neutrons. The latter, the existence of which was proved recently by Chadwick, Bothe and Becker, Irene Curie, and Joliot, etc., may indeed play a very important rôle in the final explanation of the phenomena of the cosmic radiation.

At present it is, unfortunately, not possible to distinguish with certainty the effects of photons of very high frequency and of neutrons; on the other hand the Wilson expansion-chamber method in connection with strong magnetic fields has brought very promising results (Skobelzyn, Millikan, and Anderson).

Another way of attacking the problem of the cosmic rays is the observation of the intensity-variations with altitude, geographic latitude, and time. The first mentioned are being studied at present by Regener, Kolhoerster, Piccard, and A. H. Compton. Daily and seasonal changes in the intensity of the cosmic radiation were investigated within the past nine years by Kolhoerster and von Salis, Buettner, Hoffmann, Lindholm, Steinke, Hess and Mathias, Hess and Steinmaurer, and others, who set up their instruments on mountain tops in order to observe the soft components of the radiation as well as the more penetrating ones which are prevalent at sea-level.

Kolhoerster, von Salis, and Buettner first found a regular diurnal variation with siderial time. Later observations, especially the ones by Hoffmann and Lindholm,[1] Lindholm[2] and W. Messerschmidt,[3] performed with instruments of the highest precision made the existence of this siderial-time variation rather questionable; at least it was shown that

[1]G. Hoffmann and F. Lindholm, Beitr. Geophysik, **20**, 12-54 (1928).

[2]F. Lindholm, Beitr. Geophysik, **22**, 141-163 (1929); **26**, 416-439 (1930).

[3]W. Messerschmidt, Zs. Physik, **74**, 187-190 (1932).

the amplitude of this diurnal change according to siderial time amounts to less than one per cent of the mean cosmic-ray intensity.

Several observers (Kolhoerster, Corlin, Hess, Mathias, and others[4]) found that aside from the direct influence of the barometric pressure (discovered by Myssowsky and Tuwim in 1926) on the intensity of the cosmic-ray ionization, there are other apparently irregular variations (the so-called "Schwankungen zweiter Art") the origin of which is so far unknown. All these observers agree that it is not possible to ascribe all variations in the intensity of the cosmic-ray ionization to barometric influences as R. A. Millikan and A. H. Compton believed.[5]

In 1930 the author by analyzing the very precise measurements of Hoffmann and Lindholm at Muottas Muraigl (2450m) in the Engadine (Switzerland), came to the conclusion that a very small percentage (less than 0.5 per cent) of the total effect of the cosmic rays may be of solar origin.[6] He and Pforte[7] found that observations in Halle with a most precise Hoffmann apparatus showed a maximum of the intensity at noon (local time), supporting the view that a small solar component of the cosmic radiation may exist. Messerschmidt[3] in Halle recently published results of a more extensive series of observations with the same apparatus and found that the maximum at noon was clearly discernible only during the summer months. He and Lindholm think that the solar influence on the observed rates of ionization is a secondary one, caused by the heating of the atmosphere during the day.

It seemed to the writer of utmost importance to investigate more closely this solar effect upon the observed intensities and also the diurnal, seasonal, and the irregular variations, by extended observations on a mountain top and at the same time in a nearby valley station with two similar self-registering instruments of high precision.

When in 1931 I was appointed a professor at the University of Innsbruck, a town surrounded by high mountains, I immediately planned to erect a small observatory for permanent registration of the cosmic ultra-penetrating radiation on the summit of the Hafelekar (2300 meters above sea-level), a mountain which can be reached by suspended cable railway from Innsbruck in forty minutes during the whole year. I considered this mountain preferable to the Sonnblick (3100 meters) in spite of its lesser height, since the latter, where my collaborators, O. Mathias and R. Steinmaurer, had worked during the summer of 1927 and 1929, is not always accessible in other seasons.

With the kind assistance of the Mayor and other officials of the city of Innsbruck, and the management of the "Nordkettenbahn", I succeeded in founding this small observatory on the Hafelekar, called "Station für Ultrastrahlenforschung," in the summer of 1931.

This observatory is situated in a wooden chalet exactly on the ridge of the "Nordkette." The instruments are set upon large concrete pillars in a room measuring 4.5 by 4.5 meters. This room is electrically heated and held at constant temperature by an automatic temperature-regulator. The ionization-chambers are surrounded by lead blocks 10 cm thick,

[4] W. Kolhörster, Berlin, SitzBer. Ak. Wiss, 120-125 (1925); Zs. Physik, **48**, 95-97 (1928). A Corlin, Zs. Physik, **50**, 843 (1928). V. F. Hess and O. Mathias, Wien, SitzBer. Ak. Wiss., Ia., **137**, 327-349 (1928).

[5] R. A. Millikan, Phys. Rev., **36**, 1595-1603 (1930); A. H. Compton, J. C. Stearns, R. D. Bennett, Phys. Rev., **38**, 1566 (1931).

[6] V. F. Hess, Naturw., **18**, 1094-1096 (1930); Nature, **127**, 10-11 (1931).

[7] V. F. Hess and W. S. Pforte, Zs. Physik, **71**, 171-178 (1931).

in order to screen them from the gamma-rays of the ground. The main apparatus (constructed by Dr. E. Steinke of Königsberg), standing on the west pillar, consists of a cylindrical ionization chamber of 22.6 litres capacity, filled with CO_2 at a pressure of about 9.5 atmospheres, connected with a Lindemann electrometer and a self-registering device. The ionization-current is compensated continuously in the same way as in the Hoffmann high-pressure apparatus.

A detailed description of the whole arrangement will be published soon by Dr. E. Steinke himself in *Zeitschrift für Physik*.

The photographic records of each "four-day run" can be measured and computed in an hour and a half in a very simple way without using a microscope. The records are made on photographic plates, 6 by 24 cm in size. The apparatus can run five days without attention. As a rule the operation of changing the plates, making calibrations, adjusting the compensation current according to the barometric pressure, etc., is performed twice a week. The roof of the building is kept practically free from snow most of the time in order to avoid surplus absorption of the incoming rays within the snow.

On the east pillar, parallel observations with apparatus of other types have been taken; for instance with the Kolhörster double-loop "Strahlungsapparat" and (by Dr. P. Kipfer) with the apparatus used by Professor Piccard on his first famous balloon-ascent into the stratosphere (May 1931). Parallel observations of the emanation-content and of other atmospheric elements are in progress.

In my Institute in Innsbruck (590 meters above sea-level) another high-pressure apparatus very similar to the Steinke apparatus mentioned above, was set up in April 1932 by my assistant, R. Steinmaurer, and is used continuously in order to obtain parallel measurements at a lower level. It is thought that this will give evidence as to whether the above-mentioned irregular "variations of the second kind," first studied by Corlin, occur simultaneously in both stations. The rôle of the atmospheric layers between the two stations as absorbing media can also be studied very thoroughly in this way.

Furthermore, it seemed important to organize simultaneous observations of the cosmic radiation with apparatus of the same type in other stations of different latitude. This plan was discussed during a private meeting with A. Corlin (Lund), W. Kolhörster (Berlin), E. Steinke (Königsberg), and L. Tuwim (Berlin) in Berlin (December, 1930), and met with general approval. Several other colleagues joined our "Arbeitsgemeinschaft" and at present the following stations are working with the same type of apparatus on a cooperative plan. It can be expected that within a year certain evidence will be obtained as to whether the so-called variations of the second kind occur simultaneously all over the globe. The stations are: Åbisko (Northern Sweden, 68° north latitude, operated by A. Corlin), Königsberg in Preussen (E. Steinke), Potsdam (W. Kolhörster), Dublin (Nolan and C. O'Brolchain), Innsbruck and Hafelekar (2300 meters) in Tyrol (Hess and Steinmaurer), Bandoeng in Java (J. Clay, Amsterdam), and Cape Town in South Africa (Schonland).

There is no doubt that by observations of this kind[8] it will also be

[8]The author suggested a similar organization as early as in 1913. On prearranged days simultaneous observations were taken in Vienna, Valkenburg (Holland), Innsbruck, Davos, and Graz. See Benndorf, Dorno, Hess, Schweidler, and Wulf, Physik. Zs., **14**, 1141-1144 (1913).

possible to decide with great certainty whether there is any variation in the intensity of the cosmic radiation with latitude.

The Hafelekar station has been working almost continuously with interruptions of only a few days since the end of August, 1931. I will now give a preliminary report of some results obtained during the winter of 1931 and spring of 1932. The hourly intensities of ionization, expressed in ions per cc per second, I, were reduced to normal pressure in the vessel and also reduced to the average barometric pressure on the Hafelekar of 580 mm of mercury, by means of a coefficient found empirically by plotting all I-values against the barometric pressure. The "barometric effect" thus found was on the average 0.0095 I per mm of mercury, when the apparatus was screened by 10 cm of lead all around. The average intensity was 2.802 I, for the nine-month interval, September 1931 to May 1932. On twenty days in every month the measurements were taken with 10 cm of lead all around while the remaining days were used for observations with no lead on top of the apparatus. The results of these latter will be published later.

It is important to note that the batteries (200 volts) which are in constant connection with the ionization-chamber in order to obtain saturation-current, and another battery for the auxiliary voltage of the Lindemann electrometer, were all of the Weston standard-cell type and therefore independent of the temperature. Storage-cells (packed in cotton-lined boxes) were used only for the compensation-current. The room temperature was kept constant (at 13° C.) and uniform by means of an automatic regulator and an electric fan during the whole period of nine months. Possible differences in saturation due to changes of temperature were therefore practically avoided.

The pressure in the ionization-chamber was tested several times and did not change during the whole period of observations, indicating that the vessel was free from any leaks.

In the following table the average intensities for every month are given; each figure is the mean of about 500 one-hour observations, all corrected to a barometric pressure of 580 mm and reduced to a pressure of one atmosphere in the vessel. The figures correspond to the absolute ionization in an air-filled chamber—the actual values in CO_2 were 1.5 times higher.

Ionization in ions per cubic centimeter per second (I)

Number of days	Month 1931-32	24-hour means	Day-hours alone	Night-hours alone	Midday-hours 9 a.m. to 3 p.m.
20	September	2.787I	2.790I	2.784I	2.790I
30	October...	2.798	2.799	2.797	2.800
24	November.	2.769	2.771	2.768	2.772
13	December.	2.801	2.801	2.801	2.804
16	January...	2.799	2.799	2.799	2.798
28	February..	2.841	2.842	2.840	2.844
21	March....	2.784	2.788	2.781	2.788
21	April......	2.832	2.834	2.830	2.837
13	May......	2.802	2.803	2.801	2.803

It can be seen that the monthly means are not constant, but vary by about $\pm$ 0.04 I = $\pm$ 40 mI (mI is an abbreviation for 0.001 I or one

"milli-I"). These variations no doubt are partly due to the irregular non-periodic "fluctuations of the second kind" which may cause abnormally high or low values for many days, thus affecting the monthly average, as was the case in November 1931 and in February 1932. In these months the deviations from the total mean amount to ± 1.5 per cent.

Aside from this a small increase of the intensities from winter towards spring is noticeable. A similar but larger annual variation was found by E. Steinke[9] in Königsberg; on the Hafelekar this increase is about one per cent. The data obtained so far (4500 one-hour observations) are still insufficient to derive certain conclusions about the existence or non-existence of a regular annual variation of the cosmic-ray intensities.

The fourth and fifth columns of the Table give the monthly means of the day-hours (6 a. m. to 6 p. m.) and of the night-hours (6 p. m. to 6 a. m.) separately. The day-intensities are slightly greater in seven of the nine cases. A better idea about the solar influence can be derived from the sixth column, where the means of the observations between 9 a. m. and 3 p. m. are given. These "midday intensities" exceed—with only one exception—the night intensities on the average by 4 mI (that is, 0.14 per cent), again indicating the existence of a solar effect of the same order of magnitude as found by the author, W. S. Pforte, and also by W. Messerschmidt.[10]

In order to examine this effect more closely the average values for every hour of the day were computed for three successive periods of the observations: (*a*) Autumn (September-October 1931), (*b*) winter (November-December 1931 and January-February 1932), and (*c*) spring (March, April, and May 1932). In the Figure these values are shown graphically. The ordinates indicate the deviations from the respective daily means in ± mI, the abscissae the hours (Central European time). The bottom curve (d) gives the total means of the nine-month period (4500 one-hour observations) for every hour of the day.

To the left of each curve the average error of each point of the curve, as calculated by the Gauss method, is drawn on the same scale as a vertical line. These errors amount to ± 2.5 mI (0.09 per cent of the total intensity) for a, ± 2.0 mI (0.07 per cent) for b, and ± 2.4 mI (0.09 per cent for c.

The maxima of the curves occur at 3 p. m. (September-October), 2 p. m. (November to February), and at noon (March to May); they exceed the night minima by about 8 mI (0.3 per cent of the total intensity), the daily average by 4 mI, and are certainly real since the mean errors (indicated by the vertical lines to the left of the figure) are much smaller. In the nine-month curve (d) the latter are only one third of the maximum deviations from the daily mean.

The curves are in very good agreement with the measurements of Pforte and Messerschmidt in Halle (Germany) and *prove that some solar effect* (a direct solar component of the cosmic rays or a secondary influence due to the altered scattering of the radiation in the atmosphere heated by the Sun during daytime) *does exist.* It is even quite possible that both effects exist and that towards the summer, when the Sun is high over the

[9]E. Steinke, Zs. Physik, **64**, 51 (1930).

[10]See references given before; also W. S. Pforte, Zs. Physik, **72**, 511-527, and A. Corlin and V. F. Hess Beitr. Geophysik, **31**, 169-172 (1931).

horizon the direct solar effect is more prevalent (noon maximum of the cosmic-ray intensity).

A secondary maximum between 4 and 8 a. m., slightly indicated in the figure, is within the limits of the experimental errors. Messerschmidt's curves show a secondary maximum at midnight. This is not noticeable in the Hafelekar-curves although the mean error of our nine-month curve ($\pm$ 1.3 mI = $\pm$ 0.05 per cent of the total intensity) is not greater than in Messerschmidt's series of observations.

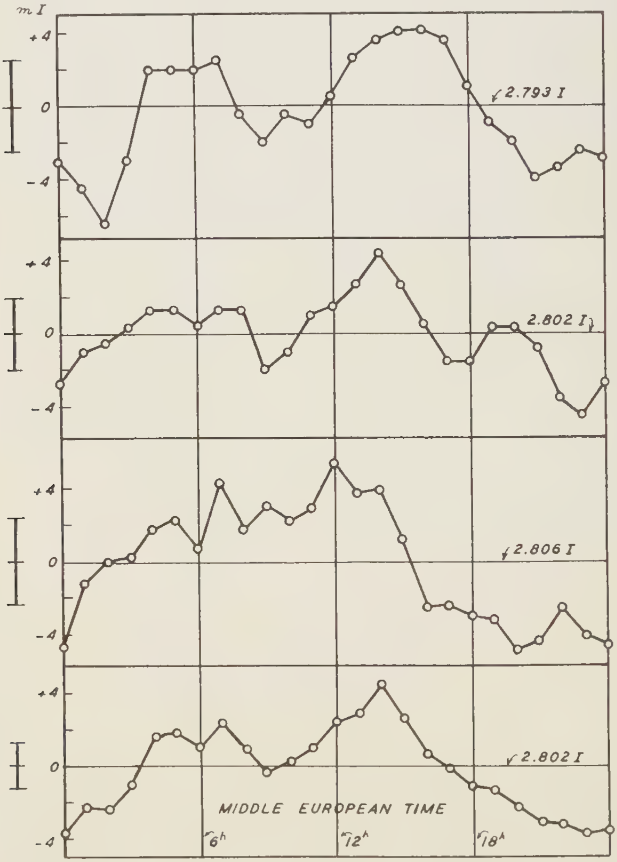


Fig. 1—Diurnal variation of the cosmic-ray intensity; graphs from top to bottom are for September-October 1931, November 1931-February 1932, March-May 1932, and September 1931-May 1932

Conclusions

(1) The average cosmic-ray intensities, as measured on the Hafelekar (2300 meters above sea-level) are not constant, but may vary from month to month by as much as $\pm$ 1.5 per cent. During the winter the intensity is slightly less than in spring.

(2) Careful examination of a nine-month record of the hourly values of the cosmic-ray intensities (September 1931 to May 1932) shows *that a solar effect certainly does exist*—at noon or shortly after noon the average intensity is by about 0.2 per cent greater than the average intensity during the night. It is concluded that both a primary effect (solar component of the cosmic radiation) and a secondary one (change in the scattering of the cosmic rays in the atmosphere, heated by the Sun in daytime) may exist. The former may prevail in summer, causing a maximum of the intensity at noon.

(3) The existence of irregular variations of the radiation ("Schwankungen zweiter Art"), sometimes extending over periods of many days, was again proved beyond doubt.

In conclusion, grateful acknowledgement is made to Dr. E. Steinke, through the use of whose apparatus, described above, the work of the Arbeitsgemeinschaft was made possible, in making simultaneous observations of the cosmic radiation over extended periods of time.

An extensive account of the observations of the Hafelekar Observatory will be published after completion of the first year in the *Sitz. Berichte der Preussichen Akademie der Wissenschaften.*

The author wishes to express his gratitude to the Prussian Academy of Science, to the Notgemeinschaft der deutschen Wissenschaft, to the Oesterreichisch-Deutsche Wissenschaftshilfe, and to the Academy of Science in Vienna for financial assistance which has made this work possible.

He also wishes to thank J. A. Fleming, Acting Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, for inviting him to contribute an article to this number in memory of the late Dr. Louis A. Bauer, his esteemed friend.

University of Innsbruck,
Innsbruck, Austria

ON THE VERTICAL COMPONENT OF THE EARTH-CURRENT IN MOUNTAINOUS REGIONS

O. H. Gish[1] has directed attention to the possibility that the vertical component of the earth-current, which flows from the base to the summit of a mountain (if supposed to carry positive electricity) may be caused by a difference in the concentration of the hydrogen-ions in the water of the soil. O. Hecker and the writer[2] in 1923 and 1924 made some series of observations on a Swiss mountain composed of dense Jurassic limestone. The electrodes, in one series of observations, were in the surface soil, and in another they were inside the mountain in old galleries in dry limestone or on good conducting ore. The values (0.05 to 0.08 volt per 100 meters) were always approximately ($\pm$ 30 per cent) the same, and not very different from the values observed by V. Oberguggenberger near Innsbruck. The meteorological conditions (rain, dry weather, heat, and cold) were such as not to have caused differences in the values of more than 5 to 10 per cent. Therefore it does not seem very probable to the writer that the water in the soil or in the rocks or the ions in this water should be the principal cause of the potential difference.

I have tried to determine whether there is a vertical component of the earth-current under a uniform surface in a salt mine in Borth near Wesel at a depth of 606 meters and in a bore-hole 150 meters deep near Freiburg i.B. There were some indications pointing to the existence of such a component at the Freiburg station only near the surface. The results in the mine were not satisfactory since the shaft contains many vertical pipe-lines and cables. The results in Freiburg were not decisive since the bore-hole was not dry but filled with water up to the surface. The water is a better conductor than the humid gneiss in which the bore-hole was made, and therefore a short circuit may equalize the potential difference.

The hypothesis of deep penetrating beta-rays, made by Swann and by H. Benndorf, at present seems the best hypothesis in explanation of the vertical earth-current. Such a current was postulated first by L. A. Bauer for the non-potential part of the Earth's magnetic field. But these beta-rays with negative charge would not have uniform velocity and wave-length but should be absorbed continuously.

Observations on the vertical current have been made only on Vesuvius and in the European Alps; their number is much too small to admit of conclusions. It is desirable to have some data from mountains in the United States. Measurements in flat country in dry bore-holes without pipe-lines would also give better experimental foundation for speculation.

J. G. Koenigsberger

[1] Ann. Rep. Dep. Terr. Mag., Carnegie Inst. Wash. Year Book 30, p. 344 (1931).

[2] Zs. Geophysik, **1**, 152 (1924).

Institute of Mathematical Physics, University,
Freiburg i. B.

THE ANOMALOUS MOUNTAIN-EFFECT IN EARTH-CURRENT MEASUREMENTS

Dr. Koenigsberger kindly referred his above note on the vertical component of the earth-current in mountainous regions to the writer for comment before publication.

Such points as he brings out will doubtless be welcomed by all, as an aid toward a better understanding of the anomaly presented by this mountain-effect in earth-current measurements. For the observations which he and O. Hecker made in mine-galleries within a mountain of Jurassic limestone the conditions which he describes are such that to explain the results due to electrochemical action is not easy.

Although the writer has suggested on various occasions that the rather consistent observation of higher potentials at lower levels may be merely an indication that in earth-materials there is a tendency for the absorbed or adsorbed electrolyte to vary with altitude or depth, it was not until about a year ago that evidence in support of this possibility came to his attention. In ecological studies made in the Great Smoky Mountains of North Carolina and Tennessee, Stanley A. Cain[1] found that the "active acidity" of the soil increased fairly regularly with altitude. Furthermore, from the hydrogen-ion coefficients (pH-values) reported by him one finds by calculation that for hydrogen electrodes the earth-potentials would decrease with altitude at the average rate of 0.1 volt per kilometer. This is of the same sign and of the order of magnitude of the observed vertical gradients (about one-fourth the average gradient found by Oberguggenberger[2]).

While this gives support to the view that the observed vertical earth-potential gradients may be merely electrochemical effects, it falls far short of establishing such a thesis. Dr. Koenigsberger is quite right in stating that the data are as yet insufficient to admit of conclusions. But the point which it is especially desired to stress is that Cain's data on the variation of hydrogen-ion concentration with altitude provides additional reason for urging that both the data and the method of obtaining them be considered more carefully than heretofore from the electrochemical point of view. There are doubtless other factors which also deserve consideration at times. Mauchly[3] expressed the opinion that pressure- and temperature-differences between the electrodes may account for some of the observations. The currents, if such there be, observed by Palmeiri on the slopes of Mt. Vesuvius may have had an origin quite different from those observed at other places. The thermal and chemical conditions of an active volcano, even when quiescent, must present great contrasts, which, along with the ever-varying mechanical stresses, may well be the seat of electrical effects. The so-called Quincke effect (electrocapillary effect) was invoked by Bachmetjew in explanation of some of his observations, and may deserve consideration as a factor in the mountain-effect.

The hypothesis that a very penetrating beta-radiation is the source of such phenomena as the "vertical earth-currents" as well as of similar currents indicated by values of magnetic line-integrals and by a presumed

[1]The Botanical Gazette, **91**, No. 1, 22-41 (1931).

[2]Wien, SitzBer. Ak. Wiss., IIa, **135**, 99-116 (1926).

[3]Terr. Mag., **23**, 73-91 (1918).

non-potential component in the general harmonic analysis of the Earth's magnetic field, does not now seem tenable. Experiments to detect such a radiation, made by Schweidler and by Swann independently, gave negative results. Furthermore, if it is admitted that the measurements of the atmospheric-electric elements are correct as to order of magnitude, as it doubtless must be, then this hypothesis only multiplies our difficulties. It would imply an air-earth current-density of from four to six orders of magnitude greater than that normally observed in the atmosphere.

Before resorting to such an hypothesis, the possible sources of error in measurement and the various terrestrial factors which may result in these apparent anomalies require very careful consideration. It is planned to make in the near future some observations designed to elucidate this mountain-effect in earth-current measurements.

O. H. Gish

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

LETTRE DE LA PART DE MM. LES PRÉSIDENTS DE LA COMMISSION INTERNATIONALE DE MAGNÉTISME TERRESTRE ET D'ÉLECTRICITÉ ATMOSPHÉRIQUE, DE L'ASSOCIATION INTERNATIONALE DE MAGNÉTISME ET D'ÉLECTRICITÉ TERRESTRES, ET DE LA COMMISSION INTERNATIONALE DE L'ANNÉE POLAIRE 1932-33, QUI A ÉTÉ ENVOYÉE À TOUS LES OBSERVATOIRES MAGNÉTIQUES ET À D'AUTRES INSTITUTIONS SUSCEPTIBLES DE POUVOIR PARTICIPER AUX RECHERCHES MAGNÉTIQUES, ÉLECTRIQUES ET D'AURORES POLAIRES PENDANT L'ANNÉE POLAIRE 1932-1933

Monsieur le Directeur,

Etant donnée l'importance des recherches magnétiques, électriques et d'aurores polaires de l'Année Polaire 1932-1933, basées sur une collaboration étendue sur tout le Globe, nous avons l'honneur de nous adresser à vous pour solliciter la collaboration de votre Observatoire en vous demandant de bien vouloir faire de votre mieux pour contribuer au succès de cette entreprise internationale.

Le programme de ces recherches est indiqué dans les deux rapports de la Commission Internationale de l'Année Polaire, publiés par les soins du Secrétariat de l'Organisation Météorologique Internationale, De Bilt, et les résolutions à ce sujet adoptés par la Commission Internationale de l'Année Polaire se trouvant également dans le Rapport de la Commission Internationale de Magnétisme Terrestre et d'Electricité Atmosphérique, publié aussi par le Secrétariat à De Bilt sous le No. 10 b.

Veuillez agréer, Monsieur le Directeur, l'expression de notre considération la plus haute.

Paris, le 22 juin 1932 — Ch. Maurain

Washington, le 25 juin 1932 — Jno. A. Fleming

Copenhague, le 30 juin 1932 — D. la Cour

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

The data for terrestrial magnetism, sunspots, solar constant, and aurora are the same as given in previous tables.

Summary American URSI daily broadcasts of cosmic data, May to July, 1932

Date	May										June**					July**					Date
	Magnetism			Sun-spot		Solar constant		Aurora*			Magnetism			Sun-spot		Magnetism			Sun-spot		
	Char.	Type	G. M. T. begin distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Char.	Type	G. M. T. begin distur.	Groups	No.	Char.	Tupe	G. M. T. begin distur.	Groups	No.	
			h m			cal.			hrs				h m					h m			
1	0	..	.. ....	1	2	1.950	f	0	0	2	1	p	.. ....	1	1	0	..	.. ....	2	6	1
2	0	..	.. ....	0	0	1.948	f	9	...	10	0	..	.. ....	1	1	0	..	.. ....	3	11	2
3	1	i	.. ....	0	0	1.959	f	0	0	0	0	..	.. ....	...	...	0	..	.. ....	2	7	3
4	0	..	16 50	...	...	1.950	u	1	1	2	0	..	.. ....	...	..	0	..	.. ....	3	11	4
5	1	p	.. ....	0	0	......	..	1	2	0	0	..	.. ....	...	...	1	i	.. ....	3	12	5
6	1	p	.. ....	0	0	......	..	9	...	10	0	.	.. ....	2	9	1	i	.. ....	1	8	6
7	0	..	.. ....	1	2	1.957	u	0	0	1	0	..	.. ....	3	12	1	p	.. ....	1	5	7
8	0	..	.. ....	1	3	......	.	0	0	1	1	p	.. ....	4	12	1	p	.. ....	1	4	8
9	0	..	.. ....	1	2	1.952	f	0	0	1	1	p	.. ....	3	12	0	..	.. ....	1	1	9
10	0	..	.. ....	1	1	......	.	9	...	10	1	i	.. ....	3	10	0	..	.. ...	1	1	10
11	1	i	.. ....	1	3	......	..	0	0	2	1	p	.. ....	2	9	0	..	.. ....	1	1	11
12	0	..	.. ....	1	1	1.954	f	9	...	10	0	.	.. ....	1	2	0	..	.. ....	1	1	12
13	0	..	.. ....	2	4	1.936	u	0	0	0	0	..	.. ....	1	1	0	..	.. ....	1	3	13
14	1	p	.. ....	4	7	1.942	u	0	0	8	0	.	.. ....	1	1	0	..	.. ....	0	0	14
15	1	..	.. ....	3	13	1.958	f	0	0	2	0	..	.. ....	1	3	0	..	.. ....	0	0	15
16	1	i	.. ....	4	15	1.947	f	0	0	1	0	..	.. ....	2	2	1	i	6 55	0	0	16
17	1	i	.. ....	4	15	1.941	u	...	...	...	0	..	.. ....	...	...	1	i	.. ....	...	...	17
18	0	..	.. ....	3	12	1.938	u	...	...	...	0	..	.. ....	2	5	0	..	.. ....	...	...	18
19	0	..	.. ....	3	9	1.942	s	...	...	..	0	.	.. ....	2	11	0	..	.. ....	0	0	19
20	0	..	.. ....	3	14	1.947	s	..	...	...	0	.	.. ....	2	11	0	..	.. ....	1	2	20
21	1	i	2	...	...	......	..	...	...	...	0	..	.. ....	2	12	0	..	.. ....	0	0	21
22	0	..	.. ....	3	4	1.936	u	...	...	...	1	b	5 15	2	9	0	..	.. ....	1	1	22
23	0	..	.. ....	4	7	......	.	...	...	...	0	..	.. ....	...	...	0	..	.. ....	0	0	23
24	1	i	23 ...	3	13	1.934	f	...	...	...	0	.	.. ....	2	6	0	..	.. ....	0	0	24
25	1	o	.. ....	2	9	......	..	...	...	...	0	.	.. ....	...	...	0	..	.. ...	0	0	25
26	1	b	7 10	...	...	......	..	...	...	...	0	.	.. ....	2	6	0	.	.. ....	0	0	26
27	0	..	21	2	4	1.848	u	...	...	...	0	.	.. ....	2	7	0	..	.. ....	0	0	27
28	1	p	18	2	2	......	..	...	...	...	0	..	.. ....	...	...	0	.	.. ....	1	1	28
29	1	p	.. ....	1	1	......	..	...	...	...	0	.	.. ...	3	11	0	..	.. ....	2	3	29
30	2	i	.. ...	1	1	......		...	...	...	0	.	.. ....	3	7	0	..	.. ....	2	3	30
31	1	i	.. ....	1	1	......	..	..	...	...						1	i	.. ....	1	3	31
Mean	0.4	..	.. ....	1.8	3.0	1.941	..	0.2	0	4	0.2	..	.. ....	2 0	6.9	0.2	..	.. ....	1.0	2.9	Mean

Greenwich mean time for endings of storms: 1[h] 50[m], May 5; 12[h], May 21; 10[h], May 25; 8[h] 45[m], May 26; 5[h], May 28; 10[h], May 31; 4[h], June 1; 11[h], June 11; 6[h] 30[m], June 22.

*Auroral observations discontinued from May 16 to August 9.

**Solar-constant observations temporarily discontinued due to instrument damage at Chile station.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots.

[1]For previous announcements see Terr. Mag.,**35,** 184-185 and 252-253 (1930); **36,** 54, 141, 258-259, and 358-360 (1931); **37,** 85-89, and 189-192 (1932).

Kennelley-Heaviside Layer heights, Washington, D. C.

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1932	*kc/sec*	*h*	*km*	*1932*	*kc/sec*	*h*	*km*
May 5	4,900	18	No value obtained	Jun. 9	5,150	19	110, 330, 480
" "	4,850	18	110, 850	" "	5,000	19	110, 290
" "	4,800	18	110, 260, 370	" "	4,600	19	110, 250
" "	4,500	19	110, 290, 490	" "	4,500	19	110, 990
" "	4,100	19	110, 290, 390	" "	4,400	19	110, 270
" "	3,500	19	110, 260	" "	4,000	19	110, 250
" "	3,300	19	110, 250	" "	3,500	19	110, 250
" "	3,000	19	110	" "	3,300	19	110, 250
" "	2,500	19	110	" "	3,200	19	110
" 11	5,150	19	No value obtained	" 24	6,100	20	No value obtained
" "	5,100	19	630	" "	6,000	20	500
" "	5,000	19	530	" "	5,500	20	100, 390
" "	4,600	20	310	" "	5,000	20	420
" "	3,900	20	110, 280	" "	4,500	20	420
" "	3,500	20	110, 230	" "	4,000	20	250
" "	3,000	20	110	" "	3,500	20	150
" "	2,500	20	No value obtained	" "	3,000	20	110
" 18	6,700	19	" " "	Jul. 1	6,000	19	No value obtained
" "	6,600	19	860	" "	5,500	19	380
" "	6,500	19	800	" "	5,000	19	490
" "	6,000	19	400	" "	4,500	19	430
" "	5,500	19	350	" "	4,000	19	200, 430
" "	5,000	19	330	" "	3,700	19	200
" "	4,500	19	260, 330	" "	3,500	19	210
" "	4,000	19	160, 290	" "	3,300	19	150
" "	3,500	20	120	" "	3,000	19	110
" "	3,000	20	120	" 7	4,500	19	No value obtained
" "	2,900	20	No value obtained	" "	4,000	19	260
" 26	5,300	20	390, 810, 890	" "	3,500	20	200
" "	5,200	20	390	" "	3,000	20	110
" "	5,000	20	330	" 14	6,000	19	No value obtained
" "	4,900	20	320	" "	5,500	19	460
" "	4,500	20	330	" "	5,000	19	320
" "	4,100	20	400	" "	4,500	19	380, 470
" "	4,000	20	140, 340	" "	4,000	20	290
" "	3,500	21	130, 250, 380	" "	3,500	20	140
" "	3,000	21	150	" "	3,000	20	130
" "	2,900	21	130	" 20	6,000	19	100
Jun. 2	6,300	20	No value obtained	" "	5,500	20	100
" "	6,200	20	430	" "	5,000	20	100, 250
" "	6,100	20	400	" "	4,500	20	100, 310
" "	6,000	20	370	" "	4,000	20	100, 290
" "	5,900	20	340	" "	3,500	20	190
" "	5,600	20	320	" "	3,000	20	110
" "	5,000	20	290	" 28	5,000	19	No value obtained
" "	4,600	20	260, 330	" "	4,800	19	290
" "	4,500	20	330	" "	4,600	19	240
" "	4,000	20	290	" "	4,400	20	250
" "	3,900	20	260	" "	4,200	20	120, 320
" "	3,600	20	230	" "	3,400	20	210
" "	3,500	20	110, 300	" "	3,200	20	120
" "	3,400	20	160	" "	3,000	20	120
" "	3,000	20	110	" "	2,800	20	120
" 9	5,200	19	110				

It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k\ (10g+s)$, where k for Mount Wilson is about 0.77. The sixth and seventh columns show (1) the value in calories of the solar constant, and (2) by letters s, f, and u, whether the determination was satisfactory, fair, or unsatisfactory, respectively.

Under the general heading of aurora in the table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

Because of the long daylight the auroral observations at Fairbanks, Alaska, were discontinued May 16 to be resumed in August. The usual details regarding form, position, etc., were possible only on May 4 and 5. On May 4 the displays were homogeneous quiet arcs without ray structure covering at the maximum 0.2 of the whole sky at average altitude of 50° from NE to E to SE with greatest display at 8^h G.M.T. On May 5 there were both homogeneous quiet arcs without ray structure and rays covering at the maximum 0.2 of the whole sky at an average altitude of 45° from NW to NE to E with greatest display at 10^h G.M.T.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, *Washington, D. C.* KATHARINE B. CLARKE

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, APRIL, MAY, AND JUNE, 1932

The only magnetic storms during the second quarter of 1932 in which the total range in H exceeded 100γ were on April 7 and May 29. The storm of April 7 was reported in the last number[1] of this publication.

Greenwich mean time		Range Hor. int.
Beginning	Ending	
1932 *h m*	*d h m*	γ
May 29..........12 ..	30 12 ..	241

On May 29 only one spot was visible. No observations were made with the spectrohelioscope on that date. On May 28 the activity of the bright hydrogen near this group had increased slightly over that observed on May 27.

[1] Terr. Mag., 37, 187 (1932).

Day	April 1932								May 1932								June 1932							
	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	1	1	1	1	0.5	1	1	1.0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
2	1	0.5	2	0.5	1	0	2	1.0	....	....	0	0	0	0	0	0.5	0	0	0	0	1	0	1	0
3	1	0	1	0	0.5	0	2	0.5	....	....	....	....	....	....	0	0.5	....	....	....	....	....	....	1	0
4	0.5	0	0.5	0	0.5	0	2	0.5	....	....	....	....	....	....	....	0.5	0	0	1	0	0	0	1	0
5	0	0	0	0	0	0	1	1.0	....	....	....	....	....	....	0	0.5	....	....	....	....	....	....	....	0
6	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0.5	1	1	1	0.5	1	0	2	0
7	0	0	....	....	....	....	0	1.5	....	....	....	....	....	....	2	0.5	1	1	1	1	1	0	3	0.5
8	0	0	0	0	0	0	0	1.0	0	0	0	0	0	0	2	0	1	2	2	2	1	0	4[f]	0.5
9	0	0.5	0	0	0	0	0	1.0	0.5	0	0	0	0	0	1	0	1	2	2	2	0	0	3	0.5
10	0	0	0	0	0	0	2	0.5	0.5	0	0	0	0	0	1	0	2	2	2	2	0	0	3	0.5
11	0	0	0	0	0.5	0	1	0	1	1	0.5	0	0	0	1	0.5	2	1	2	1	0	0	2	0.5
12	0	0	0.5	0	1	0	1	0	1	1	1	1	0	0	2	0.5	2	2	2	1	0	0	1	0
13	....	....	0.5	0.5	1	0	0	1.0	1	1	1	1	1	0.5	3[a]	0.5	1	1	1	1	0.5	0.5	1	0
14	0.5	0.5	0.5	1	0.5	0.5	0	1.0	1	2	1	1	0.5	0	4	0.5	1	0	1	0	0	0	1	0
15	0	0.5	0.5	0.5	0.5	0	1[g]	1.0	1	2	2	2	1	0	4	0.5	1	0	0.5	0	0	0	1	0
16	0.5	1	0.5	1	1	0	1	0.5	2	1	2	1	0	0	4	1.0	1	1	1	0	0	0	2	0
17	0.5	0.5	0.5	0.5	1	0	1	0.5	2	2	2	2	0	0	4	0	1	1	1	0	0	0	2	0
18	0.5	0	0.5	0	0.5	0	1	1.0	....	....	2	2	0	0	3[e]	0	1	1	1	0	1	0	2	0
19	0	0	0.5	0	0.5	0	1	0	2	1	2	2	0	0	2	0	1	1	1	0	1	0	2	0
20	....	....	....	....	....	....	....	0	2	2	2	2	0	0	3	0	2	1	2	1	1	0	2	0
21	....	....	....	....	....	....	2	0	....	....	....	....	....	....	3	0.5	2	2	2	2	0.5	0.5	2[f]	0
22	1	0	1[h]	0	1	0	2	0.5	2	2	2	2	0.5	0.5	4[d]	0	1	2	2	3	1	1	2[c]	0.5
23	1	1	1	1	1	0	1	1.0	2	2	2	2	0	0	4	0.5	1	2	2	2	1	1	2	0
24	1	1	1	1	1	0	1	1.0	2	1	2	1	0.5	1	3	0	1	2	....	....	....	....	3	0
25	....	....	....	....	....	....	.... [a]	0.5	1	2	1	1	1	2	2	0.5	1	0	2	0	0	0	3	0
26	....	....	....	....	....	....	....	1.0	2	2	2	2	0.5	0	2[b]	0.5	1	0	2	0	1	0	3	0.5
27	....	....	....	....	....	....	1	0.5	1	2	1	2	1	1	2	0.5	1	0	2	0	1	0	4	0
28	1	0	1	0	1	0	1	....	1	1	2	1	0	0	2	0.5	1	1	2	1	0	0	3	0
29	1	0	1	0	0	0	1	....	....	....	....	....	....	....	1	2.0	1	2	1	1	0	0	3	0
30	0.5	0	0.5	0	0	0	1	0	1	0	0.5	0	0	0	1	2.0	1	2	2	2	0.5	0	3[c]	0
31									0.5	0	0	0	0	0	1	0.5								
Mean	0.5	0.3	0.6	0.3	0.5	0.1	1.0	0.6	1.2	1.1	1.1	1.0	0.2	0.2	2.1	0.5	1.1	1.1	1.4	0.8	0.5	0.1	2.2	0.1

[a], [b], [c] Passage of a large group through the central meridian within 15°, 10°, 5° of the center of the disc, respectively. [d], [e], [f] Passage of an average-sized group through the central meridian within 15°, 10°, 5° of the center of the disc, respectively. [g] Passage of a small group through the central meridian within 10° of the center of the disc. [h] Small areas of very bright $H\alpha$ associated with the southeast group.

Carnegie Institution of Washington,
Mount Wilson Observatory, Pasadena, California

SETH B. NICHOLSON
ELIZABETH E. STERNBERG

PROVISIONAL SUNSPOT-NUMBERS FOR JUNE, JULY, AND AUGUST, 1932

(Dependent alone on observations at Zürich Observatory and its station at Arosa)

Day	June	July	Aug.	Day	June	July	Aug.
1	8	21[a]	9	17	16	0	0
2	0	*E* 24[c]	..[b]	18	21	8	0
3	*E* 10[c]	26	10	19	28	0	0
4	12	31	10	20	26	8	0
5	12	34	9	21	33	0	0
6	23	21[a]	8	22	27[a]	7	0
7	33	14[a]	8	23	31[a]	0	0
8	39	..	0	24	..	0	*M*13[c]
9	31[a]	..	0	25	40[d]	0	19[a]
10	31	10	8	26	30	0	22
11	32	9	0	27	26	8[d]	26
12	11	8	0	28	31	8	16
13	8	9	0	29	22	9	17
14	8	0	0	30	24[d]	9	8
15	8[d]	0	0	31	..	9	8
16	16[d]	0	0				
				Means....	22.0	9.4	6.7
				No. days.	29	29	30

Mean for quarter April to June, 1932: 17.0 (87 days).

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a larger group through the central meridan.
[c]New formation of a large or average-sized center of activity; *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland W. BRUNNER

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

APRIL TO JUNE, 1932[1]

(Latitude 57° 03'.0 N.; longitude, 135° 20'.1 or 9^h $01^m.3$ W. of Gr.)

Greenwich mean time						Range		
Beginning			Ending			Decl'n	Hor. int.	Ver. int.
1932	*h*	*m*	*d*	*h*	*m*	′	γ	γ
April 1	15	..	2	15	..	53.4	447	473
April 7	1	..	8	13	..	49.7	469	457
May 29	11	14	30	10	..	211.1	1619	1127

April 1-2, 1932—This was a small magnetic storm. There were sharp bays in all curves of the gram with an increase in value of all elements just before the third hour on April 2. This was followed by a calm, normal period until 6^h 30^m and from then until the end of the storm there were irregular bays of moderate intensity. For an hour centering just before the 13th hour the curves show small rapid oscillations.

April 7-8, 1932—This was a small storm, the *D*-curve showing a number of irregular bays with an increase in declination above normal, a gradual decrease in the vertical intensity up to the 14th hour and a

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

rather large sharp bay in the horizontal intensity at the 14th hour with a corresponding decrease in the *H*.

May 29-30, 1932—This was a major storm, the first one since the new magnetograph was installed, last November. At times the spots moved so fast that the curves were rather difficult to trace on the gram. No record was lost and ranges of much greater magnitude could be measured. The ranges in *H* and *Z* were the largest measured at this Observatory because of the increased scale-values of these two instruments. This storm was preceded by a slightly disturbed period lasting nearly a day and at the above time of beginning, large irregular bays start. The average of these bays was about 300 gammas below normal for *H*, between 300 and 400 gammas below normal for *Z* and about 20′ above normal for *D*. These bays lasted about seven hours and then they gradually became nearly normal over the next period of about four hours. There was a sharp bay in each curve around the 23d hour, May 29, and this was followed by a generally disturbed period for the next two hours. At 1^h, May 30, very rapid oscillations started, these becoming quite large in the *D*-curve. Between 3^h and 6^h on May 30 there were short periods when the curves moved so fast that it was very difficult to follow them on the gram. During the first and last parts of this period *H* was abnormally high; during the middle of this period *H* was very low, *Z* averaged below normal, and *D* averaged about normal. After 6^h the oscillations slowed up gradually and formed large bays which gradually flattened out so that the curves were nearly normal at 10^h on May 30. Franklin P. Ulrich, *Observer-in-Charge*

Cheltenham Magnetic Observatory

April to June, 1932[1]

(*Latitude 38° 44′.0 N.; longitude 76° 50′.5 or $5^h\ 07^m.4$ W. of Gr.*)

The principal magnetic storm recorded was that of May 29 to 30, regarding which some notes were published in the June number of the Journal (p. 193). The particulars there given are correct except that more careful later measurements indicate the ranges were: *D*, 71′; *H*, 477γ; *Z*, in excess of 425γ as the record went beyond the sheet.

Geo. Hartnell, *Observer-in-Charge*

Huancayo Magnetic Observatory

January to June, 1932

(*Latitude 12° 02′.7 S.; longitude 75° 20′.4 or $5^h\ 01^m$ W. of Gr.*)

There was only one major disturbance recorded during the first six months of 1932.

May 29-30, 1932—A magnetic storm of moderate intensity was recorded at the Huancayo Magnetic Observatory during May 29-30. The beginning, which was not very marked, may be placed at $11^h\ 27^m$, G.M.T. and the ending, which was equally unmarked by any sharp change, at $19^h\ 47^m$, May 30. The storm, which did not show any pronounced oscillatory movements, began with a small downward movement of the *H*-trace and then continued as a succession of small bays for nearly two hours. The movements then became larger and slower, in general being in the downward direction,

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

though a maximum was achieved at approximately the normal time. At about 19^h G.M.T. a steady decline set in, the trace descending well below the base-line and remaining so until midnight. A slight recovery occurred then, the trace rising again to the base-line, but was succeeded an hour later by a decline during which the minimum of the storm was reached. This depression lasted for about four hours and then the trace began to return to a position above the base-line. After a further three hours during which several large bays were recorded, conditions began to return to normal though the traces were still disturbed until the time at which the end of the storm has been placed. Slightly subnormal conditions prevailed until the following day. As is usual at this station, the major disturbances were recorded on the *H*-trace, though the other elements were disturbed to a proportionate amount. The recorded ranges were: *D*, 9′.2; *H*, 292γ; Z, 36γ.

PAUL G. LEDIG, *Observer-in-Charge*

WATHEROO MAGNETIC OBSERVATORY

JANUARY TO JUNE, 1932

(Latitude 30° 19′.1 S.; longitude 115° 52′.6 or 7^h $43^m.5$ E. of Gr.)

May 29-30, 1932—The storm of May 29-30, 1932, was the only magnetic storm of any magnitude recorded at the Watheroo Magnetic Observatory during January to June 1932. The beginning of the storm was recorded at 11^h 16^m in *D* and in *Z* and at 11^h 15^m in *H*, its ending being May 30 at 8^h 12^m as recorded in *D* and *Z* and at 8^h 17^m as recorded in *H*. The ranges were: *D*, 24′.0; *H*, 173γ; *Z*, 151γ.

Earthquake-disturbances, January 1 to June 30, 1932

There were no disturbances such as are usually attributed to earthquakes on the magnetograms recorded at the Observatory during January, February, and June. Such disturbances were recorded, however, in March, April, and May.

March 26, 1932—This disturbance began at 10^h 01^m, 9^h 58^m, and 10^h 03^m, and ended at 10^h 15^m, 10^h 10^m, and 10^h 16^m, with ranges of 0.9 mm, 0.4 mm, and 0.2 mm in *H*, *D*, and *Z*, respectively.

April 2, 1932—The beginning of this short-lived, small disturbance was recorded at 18^h 58^m in all three elements and ended at 19^h 02^m in *D* and *Z* and at 19^h 03^m in *H*, the ranges being 1.1 mm in *H*, 1.0 mm in *D*, and 0.7 mm in *Z*.

May 14, 1932—This disturbance was the result of a large shock approximately 500 miles northwest of Watheroo. The records, however, were so faint as to allow only approximations of the amplitudes. The disturbance began at 13^h 18^m, 13^h 17^m, and 13^h 18^m, and ended at 13^h 43^m, 13^h 36^m, and 13^h 42^m, with ranges greater than 2 mm, greater than 1 mm, and greater than 1 mm in *H*, *D*, and *Z*, respectively.

May 26, 1932—This disturbance was recorded on the magnetograms as follows: *H*, 16^h 21^m to 16^h 43^m with a range of 1.8 mm; *D*, 16^h 18^m to 16^h 38^m with a range of 0.9 mm; *Z*, 16^h 25^m to 16^h 36^m with a range of 0.3 mm. The phases were well marked on the *D*-trace and indicated distance of the quake as 3,300 miles (50°.5 of arc) from Watheroo.

All times are Greenwich mean time.

W. C. PARKINSON, *Observer-in-Charge*

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A Terrestrial and Cosmical Magnetism (Continued from page 360)

Paris, Bureau des Longitudes. Annuaire pour l'an 1932 avec des notices scientifiques. Paris, Gauthier-Villars et Cie (viii+705+A. 117+B. 146+C. 70). 14 cm. [Contains isogonic map of France for epoch January 1, 1924, and tables of magnetic declination at various stations in France reduced to the same epoch. A table of mean annual values of declination for various observatories in all parts of the world is also given.]

Patton, R. S. Magnetic work of the United States Coast and Geodetic Survey. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (156-157). [Brief report of work done during 1931-1932, under the following headings: Magnetic surveys, observatories, publications, polar year.]

Popoff, I. Die erdmagnetische Deklination in Bulgarien. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 3/4, 1932 (164-165). [Results of the determination of declination at 44 stations in Bulgaria during 1930 and 1931, are given. The values communicated apply to the times of observation.]

Purton, E. C. J. Compasses—their history, construction, and use. Tycos, Rochester, N. Y., v. 22, No. 3, 1932 (94-97).

San Fernando. Anales del Instituto y Observatorio de Marina, publicados de orden de la Superioridad. Sección 1. Observaciones meteorológicas, magnéticas y sísmicas correspondientes al año 1931. San Fernando, Imprenta del Observatorio de Marina, 1932 (ii+83 con 9 curvas). 34 cm.

Schedler, A., und M. Toperczer. Die Verteilung der erdmagnetischen Deklination in Oesterreich zur Epoche 1930.0. Wien, Jahrb. ZentrAnst. Met. Geodyn., Beiheft Jahrg. 1929, 1932 (1-22 mit 2 Karten). 28 cm. [Pub. Nr. 138.]

Spraragen, L. Magnetometer survey of Jackson area (Mississippi). Oil and Gas J., Tulsa, Okla., v. 30, No. 36, 1932 (14-15, 83-84). Abstract, Geophys. Abstr., Washington, D. C., No. 36, 1932 (419).

Stenz, E. Bericht über die magnetischen Arbeiten des geophysikalischen Instituts Lwów, 1928-1930. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 4, 1932 (409-426).

Stonyhurst College Observatory. Results of geophysical and solar observations, 1931. With report and notes of the Director, Rev. E. D. O'Connor. Blackburn, Thomas Briggs, Ltd., 1932 (xix+46). 18 cm.

Toperczer, M. Bemerkungen zur Messung der magnetischen Deklination mit Fadenaufhängung der Magnete. Wien, Jahrb. ZentrAnst. Met. Geodyn., Beiheft Jahrg. 1929, 1932 (23-30). 28 cm. [Pub. Nr. 138.]

Wallis, W. F. The geographical distribution of magnetic disturbances. Abstract, J. Wash. Acad. Sci., Washington, D. C., v. 22, No. 10, 1932 (278).

Weinberg, B. P. Catalogue of magnetic determinations in U. S. S. R. and in adjacent countries from 1556 to 1926. Part II. Leningrad, Central Geophysical Observatory, 1932 (217-295). 30 cm. [This second part is in continuation of the first volume which appeared in 1929. It contains: Addenda, corrigenda, and misprints to the tables of volume I; errata in the "Introduction"; sources (which fill a large part of the volume), alphabetical index of stations; explanation of the magnetic charts. In a separate envelope are isomagnetic charts (for declination, inclination, and horizontal intensity) for the epoch 1925. Another part of the Catalogue is promised which is to contain the magnetic data obtained during 1926-1931.]

B—Terrestrial and Cosmical Electricity

Ali, S. M. Messungen der durchdringenden Strahlung nach der Koinzidenzmethode. Göttingen, Dieterichsche Universitäts-Buchdruckerei W. Fr. Kaestner, 1931, 22 pp. 23 cm. [Inaugural-Dissertation, Universität Göttingen, 1931.]

Appleton, E. V., and R. Naismith. Some measurements of upper-atmospheric ionisation. London, Proc. R. Soc., A, v. 137, No. 831, 1932 (36-54).

BENNETT, R. D., J. C. STEARNS, AND A. H. COMPTON. Diurnal variation of cosmic rays. Phys. Rev., Menasha, Wis., v. 41, No. 2, 1932 (119-126). [The intensity of cosmic rays at an altitude of 3,900 meters was measured hourly over a consecutive period of 240 hours. The procedure eliminated the effects due to the variations of temperature and possible variations of pressure of the gas in the chamber. The ionization was about 1.5 ± 0.25 per cent more between 8 a. m. and 4 p. m. than between 8 p. m. and 4 a. m. If the variation is due to the soft component of the cosmic rays, these results are in satisfactory agreement with the results of other observers. Analysis of the data suggests that the portion of the space in the neighborhood of the Sun may emit cosmic rays more copiously than the remote regions.]

BROXON, J. W. Dependence of the ionization produced by the cosmic penetrating-radiation upon pressure and temperature. Phys. Rev., Menasha, Wis., v. 40, No. 6, 1932 (1022-1023).

BUCHTA, J. W. Cosmic rays: what are they? Physics, Menasha, Wis., v. 2, No. 5, 1932 (405-408).

CHAPMAN, S. The influence of a solar eclipse upon upper atmospheric ionization. London, Mon. Not. R. Astr. Soc., v. 92, No. 5, 1932 (413-420).

COMPTON, A. H. Variation of the cosmic rays with latitude. Phys. Rev., Menasha, Wis., v. 41, No. 1, 1932 (111-113).

DELLINGER, J. H. Radio exploration of ionization of the upper atmosphere. Abstract: Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (166-167).

FULLER, V. R. Auroral station at the Alaska Agricultural College and School of Mines. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (147).

HAMADA, H. Spectrographic observations of infra-red lines in the auroral spectrum. Nature, London, v. 130, July 2, 1932 (26).

HANSON, M. P. Kennelly-Heaviside-layer measurements on the Byrd Antarctic Expedition, 1929-30. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (167-172).

HEISENBERG, W. Theoretische Ueberlegungen zur Höhenstrahlung. Ann. Physik, Leipzig, Bd. 13, Heft 4, 1932 (430-452). [I. Das Verhalten sehr schneller Elektronen beim Durchgang durch Materie: (a) Bremsung; (b) Streuung; (c) Das Verteilungsgesetz der Sekundärelektronen. II. Absorption und Streuung harter γ-Strahlung: (a) Klein-Nishina-Formel; (b) Streuung am Atomkern; (c) Das Verteilungsgesetz der Sekundärelektronen. III. Diskussion der Experimente über Höhenstrahlung: (a) Die Skobelzynschen Aufnahmen; (b) Uebergangseffekte; (c) Koinzidenzmessungen; (d) Absorptionskurven; (e) Magnetische Ablenkbarkeit der Strahlen. Gesamtresultat.]

HULBURT, E. O. On calculations of the ionization in the upper atmosphere. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (159-160).

HUMMEL, J. N. Zur Bestimmung der Natur der Höhenstrahlung durch Koinzidenzmessungen. Physik. Zs., Braunschweig, Jahrg. 33, No. 13, 1932 (503-505).

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS. Supplements to the photographic atlas of auroral forms I. Oslo, A. W. Bröggers Boktrykkeri A/S, 1932 (37 with 12 figs. and 2 star charts). 30 cm. [This supplement gives fuller details regarding the observations of the aurora than contained in the photographic atlas of auroral forms published in 1930. It is divided into the following sections: (1) Photography of polar aurora; (2) visual observation of polar aurora, (*a*) general remarks concerning a station for visual auroral observations, (*b*), intensity, (*c*) theodolites and other means for measurement of angles, (*d*) the use of spectroscopes, (*e*) star maps; (3) guide to the sky.]

ISRAËL, H. Ergänzungen zu meiner Arbeit: Zur Theorie und Methodik der Grössenbestimmung von Luftionen. Beitr. Geophysik, Leipzig, Bd. 36, Heft 1, 1932 (24-37)

ISRAËL, H., UND L. SCHULZ. Ueber die Grössenverteilung der atmosphärischen Ionen. Met. Zs., Braunschweig, Bd. 49, Heft 6, 1932 (226-233).

JENSEN, J. C. The relation of lightning-discharges to changes in the electrical field of thunder-storms. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (190-191).
The relation of branching of lightning discharges to changes in the electrical field of thunder-storms. Phys. Rev., Menasha, Wis., v. 40, No. 6, 1932 (1013-1014).

Jevons, W. The auroral spectrum in the infra-red. Nature. London, v. 129, May 21, 1932 (759-760). [Comments on Prof. L. Vegard's letter in Nature, v. 129, Mar. 26, 1932, p. 468.]

Johnson, T. H. A calculation concerning the nature of the secondary corpuscular cosmic radiation. Phys. Rev., Menasha, Wis., v. 40, No. 3, 1932 (468-469).

Kaplan, J. Infra-red bands in the aurora. Nature, London, v. 130, July 9, 1932 (60-61).

Kato, Y., and S. Nakamura. The electric earth-potential disturbance in the seismic area of the earthquake of November 26, 1930. Sendai, Saito Ho-on Kai (Saito Gratitude Foundation), Ann. Rep., No. 7, 1931 (271-280).

Kimura, M. A consideration on the emission of the auroral green light in the night sky. Tokyo, Inst. Phys. Chem. Res., Sci. Paper No. 365, 1932 (166-176).

Lindholm, F. Registrierbeobachtungen der kosmischen Ultrastrahlung im Meeresniveau, Stockholm. Ark. Matem., Stockholm, Bd. 23 A, No. 4, 1932, 20 pp.

Mathias, E. Les éclairs globulaires et ascendants dans les montagnes et les plateaux élevés. Paris, C.-R. Acad. sci., T. 194, No. 26, 1932 (2257-2260).

Millikan, R. A., and C. D. Anderson. Cosmic-ray energies and their bearing on photon and neutron hypothesis. Phys. Rev., Menasha, Wis., v. 40, No. 3, 1932 (325-328).

Nassau, J. J. The aurora of May 30, 1932. Pop. Astr., Northfield, Minn., v. 40, No. 7, 1932 (446-447).

Piccard, A., E. Stahel, et P. Kipfer. Intensité du rayonnement cosmique à 16,000 m d'altitude. Paris, C-R. Acad. sci., T. 195, No. 1, 1932 (71-72).

Salles, E. Sur la valeur du champ électrique de l'atmosphère aux latitudes élevées. Paris, C.-R. Acad. sci., T. 195, No. 1, 1932 (68-69).

Schulze, W. M. H. Ueber die Beziehungen der Sonne zur Ultrastrahlung. Weltall, Berlin, Jahrg. 31, Heft 3, 1931 (43-45).

Polarlichterscheinungen in der Natur, in der Theorie und im Experiment. Weltall, Berlin, Jahrg. 31, Heft. 6, 1932 (73-80 mit 12 Abb.).

Simpson, J. W. The aurora of May 29, 1932. Pop. Astr., Northfield, Minn., v. 40, No. 7, 1932 (445-446).

Smith-Rose, R. L., and J. S. McPetrie. The propagation along the Earth of radio waves on a wave-length of 1.6 metres. London, Proc., Phys. Soc. v. 44, No. 244, 1932 (500-510).

Steinke, E. G., und H. Schinder. Ueber die Zertrümmerung von Materie durch Ultrastrahlung. Naturw., Berlin, Jahrg. 20, Heft 26, 1932 (491-493).

Stern, W. Beiträge zur Messtechnik und Anwendung der Methode des scheinbaren spezifischen Widerstandes. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 3/4, 1932 (181-191). [Es werden die theoretischen Grundlagen des auf Messung des "scheinbaren spezifischen Widerstandes" sich gründenden geoelektrischen Aufschlussverfahrens für horizontal geschichteten Untergrund kurz dargestellt. Die der Auswertung zugrunde zu legenden Formeln werden angegeben und diskutiert, sowohl für homogenen, isotropen, als auch für horizontal geschichteten Untergrund. Eine Messanordnung wird beschrieben und über Messungen in den Braunkohlenfeldern der Ville (Niederrhein) berichtet, deren Ergebnisse durch Kontrollbohrungen bestens bestätigt wurden.]

Störmer, C. Ein Fundamentalproblem der Bewegung einer elektrisch geladenen Korpuskel im kosmischen Raume. Dritter Teil. Zs. Astroph., Berlin, Bd. 4, Heft 4, 1932 (290-318). [Es werden in diesem dritten Teil weitere Reihenentwicklungen der Integrale der Bewegungsgleichungen gegeben, die nützlich für numerische Berechnungen sind. Weiter werden die für grosse Entfernung vom Dipol sehr angenäherten Integrale näher studiert und die Integrationskonstanten übereinstimmend mit den Anfangsbedingungen bestimmt. Zuletzt folgen Anwendungen auf die kraftlose Bewegung, auf die Gravitation und auf den Fall mit Dipol allein.]

Fortschritte in der Nordlichtphotographie. Physik. Zs., Leipzig, Jahrg, 33, Nr. 14, 1932 (543-544).

SUCKSTORFF, G. A. Neue Messungen der Höhenstrahlung in grösseren Höhen. Naturw. Berlin, Jahrg. 20, Heft 27, 1932 (506).

TUWIM, L. Einige prinzipielle Bemerkungen über Versuche mit Höhenstrahlungskoinzidenzen. Zs. Physik, Berlin, Bd. 76, Heft 7/8, 1932 (561-564). [Es wird gezeigt, dass nach der mathematischen Theorie der Höhenstrahlungskoinzidenzen und des vertikalen Zählrohreffekts der Höhenstrahlung das Auflösungsvermögen von Zählrohranordnungen nicht durch den Raumwinkel der Zählrohre gegeben ist, wie es ohne Berücksichtigung der Zählrohreffekte zu erwarten wäre, sondern mit Erhöhung der Messgenauigkeit unbegrenzt gesteigert werden kann.]

WAIT, G. R., AND O. W. TORRESON. Slow-moving ions in the atmosphere. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (182-187).

WELD, L. E. Analysis of cosmic-ray observations. Phys. Rev., Menasha, Wis., v. 40, No. 5, 1932. [A method of rendering non-linear observation equations susceptible to least-square adjustment is adapted to observations on the absorption of cosmic rays in bodies of water, data on which have appeared from time to time; the object being to obtain the most probable values of the constants of the assumed discrete components of the radiation. Applied to the most consistent data so far published, viz., those reported by Millikan and Cameron in 1931, the adjustment shows that the quantitative conclusions deduced from them by the observers are not derivable from the data by the method of least-squares.]

WHIPPLE, F. J. W., AND OTHERS. The maintenance of the Earth's electric charge. Observatory, London, v. 55, No. 697, 1932 (167-172). [Summary of views expressed at meeting for the discussion of geophysical subjects, held in the Royal Astronomical Society's rooms, London, April 29, 1932.]

C—Miscellaneous

ABBOT, C. G. Solar-constant work by the Smithsonian Institution. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (155). [Very brief progress report.]

ALMY E. D. Work related to terrestrial magnetism and electricity of the Naval Research Laboratory. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (158).

BARTELS, J. Tides in the atmosphere. Sci. Mon., New York, N. Y., v. 35, No. 2, 1932 (110-130).

BENNETT, R. D., N. G. KEAR, AND W. S. HUTCHINSON. Massachusetts Institute of Technology. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C .,1932 (153-154). [Reports on the work being done under the following headings: (a) Cooperation in the cosmic-ray survey, (b) the elimination of night-course variations in radio range-beacons, (c) developments in geophysical prospecting by electrical-potential methods.]

BLACKWELL, O. B. Work of the Bell System relating to terrestrial magnetism and electricity during 1931. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (148).

FISK, H. W. Summary of reports received on magnetic and electric work of organizations in the United States during 1931-32. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, 1932 (145-147).

GHERARDI, W. R. Work of the United States Hydrographic Office in terrestrial magnetism and electricity. Trans. Amer. Geophys. Union., 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (157-158).

GLANVILLE, W. E. Zodiacal light notes. Pop. Astr., Northfield, Minn., v. 40, No. 7, 1932 (439-441).

GROTEWAHL, M., UND A. SCHOLZ. Das Internationale Polarjahr 1932/33. Weltall, Berlin, Jahrg. 31, Heft 7, 1932 (89-93).

HEILAND, C. A. Colorado School of Mines. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (153). [Brief statement of the research work in geophysics under way at the Colorado School of Mines, March 1932.]

Israël, H. Ergänzungen zu meiner Arbeit: Zur Theorie und Methodik der Grössenbestimmung von Luftionen. Beitr. Geophysik, Leipzig, Bd. 36, Heft 1, 1932 (24-37).

Kenrick, G. W., and G. W. Pickard. Some common periodicities in radio transmission-phenomena. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (172-179).

Koenigsberger, J. Thermoremanenz und spontane Magnetisierung. Physik. Zs., Leipzig, Jahrg. 33, No. 12, 1932 (468-474).

Köppen, W., und R. Geiger. Handbuch der Klimatologie. Band IV, Teil S. Australien und Neuseeland. Berlin, Verlag von Gebrüder Borntraeger, 1932 (vi+137). 26 cm. [Climatology of Australia, by Griffith Taylor; Climatology of New Zealand, by E. Kidson.]

Kumpe, G. E. United States Signal Corps. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (158-159). [Brief statement of study of cosmic data in relation to results obtained from Signal Corps radio transmission.]

Milne, E. A. The white dwarf stars. Being the Halley Lecture delivered on 19 May 1932. Oxford, Clarendon Press, 1932 (32 with 3 figs.). 23 cm. Price 85 cents. [A detailed exposition of the present status of our knowledge regarding the small class of abnormally white stars known as "white dwarfs" based on results of recent astrophysical research, with a discussion of the successive advances made beginning with Halley and Bessel.]

Mount Wilson Observatory. Summary of Mount Wilson magnetic observations of sunspots for March and April 1932. Pub. Astron. Soc. Pacific, San Francisco, Cal., v. 44, 1932 (188-190).

Piggot, C. S. Radium-content of ocean-bottom sediments. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (233-238).

Schafer, J. P., and W. M. Goodall. Kennelly-Heaviside layer studies employing rapid method of virtual-height determination. New York, N. Y., Proc. Inst. Radio Eng., v. 20, No. 7, 1932 (1131-1148).

Stetson, H. T. Progress in the studies of cosmic correlations with radio reception at the Perkins Observatory. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (180-181).

Turner, S. Geophysical work at the United States Bureau of Mines. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (155-156). [Brief statement of work done during the year ended March 1932.]

Tuve, M. A. The geophysical significance of radio measurements of the ionized layer. Trans. Amer. Geophys. Union, 13th Annual Meeting, Nation. Res. Council, Washington, D. C., 1932 (160-166).